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Pre-COSEWIC review of barndoor skate *Dipturus laevis* in the Canadian Atlantic

Examen pré-COSEPAC concernant la grande raie (*dipturus laevis*) de l'Atlantique canadien

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ABSTRACT

A Department of Fisheries and Oceans (DFO) review of Canadian standardized research vessel (RV) surveys, industry/science surveys and observer records in 2002 suggested that barndoor skate was sufficiently numerous to ease concerns about its conservation status. They were more widely distributed than previously thought and consistently captured at depths/locations beyond the standard research vessel surveys. This document updates the Canadian RV and industry science information, revisits earlier observer reports and looks at the US RV surveys in more detail. A review of recent biological studies revealed that growth was faster, females matured earlier (approximately 7 years), and the species is more fecund than previously thought. USA RV surveys indicate the species is most common from just south of Georges Bank to the Gulf of Maine. Canadian RV surveys indicate the species is most common on Georges Bank west to Sable Island on the Scotian Shelf and on the southern flanks of the Scotian Shelf and the Grand Banks. They are rare north of these areas. Observer reports that the species was distributed as far north as the Davis Strait were reexamined and found to be incorrect. Population estimates from the Canadian and USA RV surveys for Georges Bank and the Scotian Shelf suggests that abundance has been increasing at an annual rate on 3-14% per year since 1996. Abundance is now approaching or has exceeded estimates seen in the 1960s to mid 1970s. As the population rebounded, the species has expanded first from relatively small areas on Georges Bank, to the whole of the bank, then Northwest Atlantic Fisheries Organization (NAFO) Division 4X and recently back into Division 4W. There are no directed fisheries for barndoor skate in Canadian waters; however, the species is caught as a bycatch in other fisheries. An examination of the landings in these other fisheries suggest that the declines observed in barndoor skate abundance in the 1960s on Georges Bank were coincident with a peak in landings, but not in the other NAFO divisions. The recent increases in RV abundance on Georges Bank and the Scotian Shelf are occurring during times when groundfish landings are low. The population collapse observed in the late 1960s and 1970s appears to have been reversed and the review of these data suggests that the species has recovered to population sizes seen in the 1960s. The reasons for the collapse and subsequent recovery are uncertain but the status of this species must continue to be monitored as it has shown that it is vulnerable to significant population declines in the past.

RÉSUMÉ

Un examen du ministère des Pêches et des Océans (MPO) des relevés normalisés des navires de recherche canadiens, des relevés de l'industrie et du Secteur des sciences ainsi que des relevés des observateurs en 2002 laissent croire que la grande raie est actuellement suffisamment abondante pour que l'état de sa conservation soit moins préoccupant. Cette espèce est répartie à grande échelle contrairement à ce que l'on croyait précédemment et régulièrement capturée à des profondeurs/endroits échappant aux relevés habituels des navires de recherche. Ce document présente une mise à jour concernant les navires de recherches canadiens et l'information de l'industrie et du Secteur de la science. Il réexamine les rapports précédents des observateurs et étudie minutieusement les relevés des navires de recherches des États-Unis. Il ressort d'un examen des études biologiques récentes que la croissance était plus rapide, les femelles atteignaient précocement leur maturité (environ 7 ans) et que l'espèce était plus féconde que l'on ne l'avait cru auparavant. Les relevés des navires de recherche des États-Unis indiquent que l'espèce est plus répandue à partir du sud du banc Georges jusqu'au golfe du Maine. Les relevés des navires de recherche canadiens montrent que l'espèce est plus abondante dans la région couvrant l'ouest du banc Georges jusqu'à l'île de Sable dans le plateau néo-écossais et sur les versants sud du plateau néo-écossais et dans les Grands Bancs de Terre-Neuve. L'espèce est rare dans le nord de ces régions. Les rapports des observateurs indiquant que l'aire de répartition de l'espèce s'étendait aussi loin au nord que le détroit de Davis se sont avérés incorrects après réexamen. Les estimations de population des relevés des navires de recherche canadiens et des États-Unis pour le banc Georges et la Plate-forme de Scotian laissent croire que l'abondance augmente à un taux annuel de 3 à 14 p. 100 depuis 1996. Actuellement, l'abondance de l'espèce approche les estimations enregistrées entre les années 1960 et le milieu des années 1970 ou qu'elle les aurait dépassées. Étant donné que la population a augmenté, l'espèce s'est répandue à partir des superficies relativement petites dans le banc Georges jusqu'à l'ensemble du banc, pour continuer ensuite dans la division 4X de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO) et récemment, elle est revenue dans la division 4W. Il n'existe pas de pêches dirigées pour la grande raie dans les eaux canadiennes. Cependant, l'espèce est capturée accidentellement dans le cadre d'autres pêches. Un examen des quantités débarquées dans le cadre de ces pêches laisse croire que les déclins observés dans l'abondance de la grande raie dans les années 1960 dans le banc Georges coïncidaient avec la quantité débarquée qui a atteint un sommet, mais pas dans d'autres divisions de l'OPANO. Les augmentations récentes de l'abondance des navires de recherche dans le banc Georges et dans le plateau néo-écossais surviennent durant les périodes pendant lesquelles les quantités débarquées de poisson démersal sont peu élevées. Le processus de déclin de la population observé vers la fin des années 1960 et 1970 semble être inversé et l'examen de ces données porte à croire que l'espèce s'est rétablie pour atteindre la population observée dans les années 1960. Les raisons expliquant ce déclin et le rétablissement subséquent sont mal connues, mais l'état de l'espèce doit faire l'objet d'une surveillance continue, car elle a démontré dans le passé qu'elle était vulnérable lorsque la population subissait un déclin important.

INTRODUCTION

The barndoor skate (*Dipturus laevis*) is reported to be the largest skate in the northwest Atlantic, growing to a length of about 1.5 m and 20 kg in weight (Scott and Scott, 1988; MacEachern, 2002). It is one of a group of closely related species that includes *Dipturus batis* in European waters and *D. floridana* off the southern United States (Bigelow and Schoeder, 1953). Its reported range extends from as far north as southwestern Grand Bank and the southern Gulf of St. Lawrence, south to waters off northeastern Florida (Scott and Scott, 1988) (Figure 1). McEachran and Musick (1975) suggested that the most southerly records may have been a misidentification of *D. floridana* and that *D. laevis* may not occur south of Cape Hatteras. Within this broad geographic range, barndoor skate have been reported from the tide line (and even stranded above it: Bigelow and Schroeder, 1953) to depths of 430 m.

The World Conservation Union (IUCN) assessed the status of barndoor skate in 1994 as vulnerable. Casey and Myers (1998) evaluated its historical and contemporary status and concluded that the species was currently near extinction. Following its publication, the U.S. National Marine Fisheries Service was petitioned in 1999 to consider barndoor skate as a candidate for listing under the Endangered Species Act (ESA). Evaluation of the status of barndoor skate in USA waters relative to the five listing factors of the ESA led to the conclusion that "there was no evidence that they were in danger of extinction or likely to become endangered within the foreseeable future throughout all or a significant portion of its range." (NMFS, 2000, 2002), but landings of this species in the USA were prohibited in 1999. Nevertheless, the IUCN, in its 2003 re-assessment of the species, concluded that it was endangered due in part to its life history characteristics (Dulvy, 2002; Dulvy, 2003; Frisk et al., 2002).

In 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) called for a review of the status of this species to determine whether it may be at risk in Canadian waters. In preparation for this review by COSEWIC, the Department of Fisheries and Oceans (DFO), as the Department responsible for marine species, was required to summarize all known information on the species. In 2002, two research documents were produced that summarized the known information to date. The first summarized the research vessel (RV) and industry survey information (Simon et al., 2002) while the other summarized bycatch information from commercial fisheries (Kulka et al., 2002). The RV document observed that abundance had been increasing since the mid-1990s in the Gulf of Maine/western Scotian Shelf (Northwest Atlantic Fisheries Organization (NAFO) divisions 5Z, 4X) areas, but were no longer evident on the eastern Scotian Shelf (Divs. 4VW), Subdiv. 3Ps, or the southwestern slope waters of the Grand Banks (Divs. 3NO). They concluded that the species was sufficiently numerous to ease concerns about its conservation status (Simon et al., 2002). Kulka et al. (2002) reported that the species was widely distributed, as far north as the Labrador Shelf to 62°N and into depths of about 1600 m based on observer reports in various fisheries. Given the depth range in which they were observed, it was felt that the research surveys indices may not reflect changes in the total population of the species if they only reflect what occurred on the fringe of the population. Because most of the fishing effort in the southern part of the range was < 450 m, this deepwater stratum may have provided some protection to the population and provides a source of individuals to recolonize the surveyed area.

Since 2002, a number of publications (Gedamke et al., 2005; Gedamke, 2006; Parent et al., 2008; Packer et al., 2003) have substantially improved the knowledge base on the distribution, abundance and life history of barndoor skate. Although the life history information is based on barndoor skate from USA waters, it has been very useful in guiding this analysis.

This research document represents a comprehensive re-examination of the DFO RV and industry surveys, and extends the analysis to include USA RV surveys that provides information on the occurrence of barndoor skate in the broad geographic area between Georges Bank and northern Labrador (Figure 1). Based on potential species identification problems that were discovered after Kulka et al. (2002) was published, the bycatch data from commercial fisheries in the Newfoundland and Labrador Region was re-examined and range estimates were revised. On the western Scotian Shelf and Georges Bank, estimates of removals by traditional fisheries were calculated.

METHODS

Life History Characteristics

A comprehensive study on the biology of barndoor skate was conducted in 1999, 2000, and 2001 (Gedamke et al., 2005; Gedamke, 2006) and was based on 2,310 fish that were collected from Closed Area II (which is adjacent to the international boundary with Canada) on Georges Bank (Div. 5Z) (Figure 2). This area was closed to draggers in 1994 and reopened to limited scallop fishing in 1999; it was from this gear sector that the samples were collected. Growth parameters were developed and observations on length at maturity were made. These parameters are compared to a small-scale biological study on barndoor skate from Div. 4W conducted in 2001 (Simon et al., 2002).

Parent et al. (2008) reported on the captive breeding of barndoor skate at the Montreal Biodome. Five individuals were acquired in 1997 and, after 6.5 years, the single remaining female began producing skate purses. Annual estimates of fecundity and incubation times were recorded from 2003-2007. As well, growth in captivity was compared with growth estimated by Gedamke et al. (2005).

Overview of Canadian RV, Industry/Science, and USA Survey Information

DFO Research Vessel Surveys

Research survey data from four different DFO Regions were examined : 1) Newfoundland and Labrador (NL); 2) Quebec; 3) Gulf; and 4) Maritimes, as well as USA seasonal surveys extending from Cape Hatteras to Div. 4X. Given the regional nature of survey activity by Fisheries and Oceans, this information was presented on a regional basis. This administrative separation has led to differences in the seasons and years surveyed, as well as differences in trawl gears that have different catchability. Figure 1 illustrates the delineation of these regions, and the statistical NAFO Divisions that are traditionally used in commercial fishery assessments to subset these areas. However, all regions use trawl gear and a stratified random survey design. The following sections summarize the major regional differences in survey time periods, gears, and seasons, which were considered in more detail in Kulka et al. (2006). These surveys cover most of the known range of barndoor skate with the exception of the slope waters deeper than the survey strata.

Quebec Region (Div 4RS, Subdiv. 3Pn)

Bottom trawl groundfish surveys from the Quebec Region were examined, separated by differences in vessel, gear, time of year, and area surveyed. This has resulted in the creation of four RV series for the Region dating back to 1978. In general, the surveyed area included the northern Gulf (Div. 4RS), as well as the southeast Gulf (Subdiv. 3Pn). In all cases, the sampling

methodology followed a depth-stratified random survey design, but conversion factors do not exist between series (Kulka et al., 2006).

The winter surveys were conducted by the *Gadus Atlantica* from January 1978 to 1994 using an Engels 145 trawl. The area surveyed varied over the series, mainly due to ice cover preventing fishing. The average area covered is 62,550 km^2 with the smallest area in 1992 amounting to 31,737 km^2 and the largest in 1980 at 100,400 km^2. Coverage of Subdiv. 3Pn and Div. 4R was good over the series, while coverage in Div. 4S was more variable (Kulka et al., 2006).

Summer (August) RV surveys have been conducted in the northern Gulf since 1984 using a variety of vessels, gears, and areas surveyed. From 1984 to 1990, the survey was conducted by the *Lady Hammond* using Western IIA trawl gear. Total surveyed area (Div. 4RS) was fairly constant from 1985 to 1989 averaging 95,700 km^2; however, in 1984 and 1990, coverage was reduced (Kulka et al., 2006). From 1990 to 2005, the survey was conducted on the *Alfred Needler* equipped with a URI (University of Rhode Island) shrimp trawl. Additional shallow strata (20-50 fathoms) were added at the onset of the *Alfred Needler* survey. Over the series, the surveyed area averaged 111,300 km^2. The minimum area surveyed was in 1990 with 95,070 km^2 and the maximum area surveyed in 1995 with 119,000 km^2. Subdiv. 3Pn was sampled from 1994 to 2003 (Kulka et al., 2006). Since 2005, the northern Gulf of St. Lawrence has been surveyed by the *Teleost* equipped with Campelen gear. The area surveyed varied from 91,600 to 116,115 km^2, but Subdiv. 3Pn was not surveyed.

Gulf Region (Div. 4T)

Data are from annual bottom trawl surveys conducted in the southern Gulf of St. Lawrence each September since 1971. Surveys use a stratified random design with stratification based on depth and geographic region. Surveys were conducted using a Yankee 36 trawl from 1971 to 1984 and a Western IIA trawl since 1985. The research vessels conducting the survey were the *E. E. Prince* from 1971 to 1985, the *Lady Hammond* from 1985 to 1991, the *Alfred Needler* from 1992 to 2002, the *Wilfred Templeman* in 2003, and both the *Alfred Needler* and the *Teleost* in 2004 and 2005. Fishing was conducted only during daylight hours (07:00-19:00) in 1971-1984, but 24 hours per day since 1985. Where applicable, catches were adjusted for diel differences in fishing efficiency as described by Benoît and Swain (2003).

Newfoundland and Labrador Region (SubArea 23)

Stratified-random surveys have been conducted by Canadian research vessels in the spring (April to June period) of each year from 1971 to 2008. A summary of the stratified-random survey design adopted by the DFO-NL Region was reported by Doubleday (1981). While survey design has remained constant, additional strata have been included in recent years, along with modifications to some of the original strata (Bishop 1994). A significant change in the surveys is the addition of shallower and deeper strata after 1993. The spring survey can be split into 3 time periods based on the trawl used in each period: 1971-1982 (Yankee gear, vessel: *A.T. Cameron*), 1983-1995 (Engels gear, vessels: *Alfred Needler*, *Wilfred Templeman*), and 1996-2007 (Campelen gear, vessels: *Alfred Needler*, *Wilfred Templeman*, *Teleost*).

Stratified-random autumn surveys have been conducted by Canada in Div. 2J3K from 1977 to present (vessels: *Gadus Atlantica* [to 1994], *Teleost*, *Wilfred Templeman* [since 1995]) and in Div. 3L (vessels: *A.T. Cameron*, *Wilfred Templeman*, *Teleost*) from 1981 to present. In 1990, autumn surveys also extended onto the southern Grand Banks in Divs. 3NO. Surveys were conducted with an Engel trawl during 1983-1994 and with a Campelen trawl during 1995-2007. It must be noted that Canada does not survey Subdiv. 3Ps in autumn and did not survey Divs.

3NO before 1990. Furthermore, autumn surveys reach deeper maximum depths (~1,400 m in recent years) than those in spring (~750 m).

Maritimes Region (Divs. 4VWX, 5Ze)

The DFO summer survey has been conducted annually on the Scotian Shelf (Divs. 4VWX) since 1970 using a stratified random design based on depth and geographic area (Figure 3). In 1995, coverage was expanded into three deepwater strata (365-732 m) on the edge of the shelf, but they have not been included in these analyses because barndoor skate have not been caught in these strata. From 1970 to 1981, the survey was conducted by the *A.T. Cameron* using a Yankee 36 trawl. In 1982, the *A.T. Cameron* was replaced by the *Lady Hammond* using the Western IIA as the new standard trawl. In 1983, the *Lady Hammond* was replaced by the *Alfred Needler* using the Western IIA trawl. In 2004, the *Alfred Needler* was replaced by the *Teleost* due to a fire on the *Alfred Needler*. The 2005 survey was conducted by both the *Teleost* and the *Alfred Needler* to investigate differences in catchability between the two vessels but due to the very low number of individuals encountered, this has not been investigated for barndoor skate. In 2006, the survey was conducted by the *Alfred Needler*. In 2007, the survey reverted back the *Teleost* and in 2008, the sister ship of the *Alfred Needler*, the *Wilfred Templeman* conducted the survey.

The February/March RV survey on Georges Bank (Div. 5Ze), commenced in 1986 using Western IIA trawl gear and a stratified random design (Figure 3). The *Alfred Needler* has been the primary vessel except in 1993 and 2004 when its sister ship the *Wilfred Templeman* was used. The survey concentrates on the Canadian side of the bank (Subdiv. 5Zc) with additional sets on the USA side of the EEZ that cover the remainder of the bank as well as stations north of the bank.

The 4VWCOD (spring) survey has been conducted since 1986 on the eastern half of the Scotian Shelf (Div. 4VsW). This survey uses a stratification scheme that was meant to optimize the abundance estimates of cod. During 1986-2003 and 2005-2006, the survey was conducted by the *Alfred Needler* using the Western IIA trawl. No surveys were conducted in 1998 or 2004. The 2007 survey was conducted by the *Teleost* using a Western IIA trawl. Deep water strata (365-549 m) in the Laurentian Channel were added to this survey in 1993 and although not included in abundance trend analysis, the catches in these strata are included in the distribution maps.

USA Research Vessel Surveys (Div. 4X, SubArea 56)

Research surveys of the east coast of the USA and the southern half of the Scotian shelf have been conducted by NMFS each fall since 1963 and each spring since 1968. Both surveys use a stratified random design similar to the Canadian DFO summer RV survey (Figure 4). Two research vessels the *Albatross IV* and the *Delaware II* have been the primary survey vessels with the *Atlantic Twin* surveying the inshore areas from autumn 1972 to spring 1975. Generally, a Yankee 36 has been the standard survey gear except a modified Yankee 41 was used during the spring survey from 1973 to 1981. In addition, there was a change in the trawl doors in 1985. No conversion factors are available for this species for any of the changes that occurred during either survey series. Data from a winter RV survey (2000-2006) that uses a similar survey design to the other seasonal surveys but uses a chain sweep with small cookies to better target flatfish are presented for comparison. In addition, a distribution plot is presented from the NEFSC Scallop Survey.

Canadian Industry/Science Surveys

Three industry/science surveys based in the Maritimes Region and conducted since the mid 1990s were also evaluated. These surveys have standard sampling designs. The industry participants have undergone training for sampling methods and species identification and, in addition, trained observers have been deployed on a majority of the participating vessels.

The Individual Transferable Quota (ITQ) Fixed Station Industry Survey in Div. 4X began in the summer of 1995. This survey is conducted by four otter trawlers using a balloon trawl that has smaller diameter footgear than the RV survey gear and, therefore, potentially higher catchability of barndoor skate. The area sampled is similar to the RV survey except the area inshore of the 50 fm line is also surveyed.

The Div. 4VsW Sentinel Survey is a stratified random longline survey conducted by industry participants. The series began in fall 1995 and includes all areas surveyed by the RV survey in Div. 4VsW as well as three additional inshore strata. In 2005, the survey was reduced to those three inshore strata as well as four core strata that were thought to be the centre of distribution for haddock. Skate were not identified to species until 1996 so our analysis begins in that year.

The Halibut Industry Survey began in 1998 using longline gear primarily on the Scotian Shelf with sets extending into the southern portion of the Grand Banks. An index fishery conducted by the same participants, fished in waters deeper than the regular survey, primarily in the slope waters of the Scotian Shelf and the Grand Banks. Details on location, gear type, time of year, duration, and sampling effort are described by Armsworthy et al. (2006).

Area Occupied

This section provides information on the trends in design weighted area occupancy (DWAO) within the Maritimes Region (Divs. 4VWX and 5Z) based on the DFO annual bottom-trawl surveys in those areas.
Area of occupancy (A_t) was calculated for year t as follows:

$$A_t = \sum_{i=1}^{n} a_i I \quad \text{where } I = \begin{cases} 1 \text{ if } Y_i > 0 \\ 0 \text{ otherwise} \end{cases}$$

where n is the number of tows in the survey in year t, Y_i is the number of barndoor skate caught in tow i, and a_i is the area of the stratum fished by tow i divided by the number of sites fished in that stratum (Smedbol et al., 2002). Given the relatively few sets in an annual survey that capture barndoor skate, the DWAO index will be low in relation to the total area surveyed. Catches of barndoor skate in the other regions were insufficient to calculate meaningful estimates of occupancy.

Habitat Associations

Ecosystem Considerations

Gedamke's (2006) analysis of the diet of barndoor skate in Div. 5Z was compared with stomach information from barndoor skate on the Scotian Shelf. This analysis has identified a number of major prey items and the abundance of these species were compared with the abundance of barndoor skate the USA RV fall survey to provide some comparative measure to possibly help

understand the collapse and then apparent recovery of barndoor skate. Details of this analysis can be found in Appendix A.

Essential Habitat

In 2003, NOAA reviewed the life history and habitat characteristics of barndoor skate as part of their essential habitat series (Packer et al., 2003). At the time, Gedamke's (2006) thesis was incomplete and they summarized the limited information to that date. Packer et al. (2003) used background information from Bigelow and Schroeder (1953) on distribution and biology of the species, and the predictive equations by Frisk et al. (2001), to estimate that barndoor skate matured at approximately 102 cm. Distribution maps using this length as a break point were produced that were meant to represent juvenile and adult abundance.

For this document, distribution by length category were produced from the RV surveys in the Maritimes Region, based on the more recently observed life history characteristics reported by Gedamke (2006) and the limited observations by Simon et al. (2002). Abundance estimates for large bodied species, such as this, are commonly reported in 3 cm bins that do not allow one to exactly disaggregate the annual length frequencies into juvenile and adults by the overall reported length of 50% maturity of 112 cm. Therefore, a break point of 114 cm in the length frequency bins was chosen, which is closer to the female length at 50% maturity than the male estimate. Since these estimates are primarily from Div. 5Z, growth is likely to be slower on the Scotian Shelf. As well, distribution plots were produced that would approximate nursery areas by observing where age 0 (<40 cm) individuals were distributed.

Packer et al. (2003) summarized the known depth, temperature, and salinity preferences for the species from the literature and some RV data. On the Scotian Shelf and Georges Bank, detailed information of these parameters are collected as part of the RV surveys. These data are summarized for both surveys and compared with the respective RV catches of barndoor skate in those surveys.

Reported Bycatch from Commercial Fisheries

An examination of commercial fisheries data by Kulka et al. (2002) reported that barndoor skate were more widely distributed and at a much greater depth than had been previously described. They were reported as far north as the Labrador Shelf to 62°N and out to a depth of 1600 m. These observations were based on combined observer reports from the Newfoundland and Maritimes Regions. It was later noted that there were discrepancies in species identification between the observers from the two regions. Samples identified as barndoor skate were collected from a number of fisheries and returned to the Newfoundland office for confirmation. These samples indicated that there was a potential problem in the identification of barndoor skate especially from fisheries north of 50°N and at depths greater than 1000 m. An intensive species identification program was developed for observers. New species ID cards were created that have greatly improved confidence in observer reports of barndoor skate.

Threats

Given the demersal nature of this species, landings from all groundfish by all countries combined since 1960 are reported from Divs. 5Z, 4X, 4VW, and Subdiv. 3Ps. This is meant to be a proxy for total groundfish effort in these divisions and would represent the relative fishery pressure that would be faced by barndoor skate. Although usually a bycatch species and discarded by Canadians, foreign fisheries have retained skate for meal in the past.

Directed Canadian fisheries on skate have existed on the Newfoundland Shelf and on the eastern Scotian Shelf since 1994, but these fisheries directed for thorny and winter skate respectively and barndoor skate make up an insignificant percentage of the catch. The directed fishery on the Scotian Shelf was closed in 2005.

A detailed examination of observer records from 1996 to 2005 in Div. 5Z and Div. 4X was used to estimate bycatch of this species in a number of fisheries (unpublished DFO data). Bycatch rates were calculated for the primary fisheries in these areas and annual total bycatch was calculated for each division. Relative F's (fishing mortality) were calculated by dividing the total biomass from the RV survey by the total bycatch in each division.

RESULTS

Life History Characteristics

Of the 2,310 fish examined by Gedamke et al. (2005), only 87 individuals were determined to be mature based on a visual inspection of the reproductive organs. Length at 50% maturity (Lmat) for females was 116.3 cm while males matured at 107.9 cm. The combined length at 50% maturity was 112 cm. A preliminary analysis of 118 vertebrae (two readers) revealed faster growth (k=0.14 to 0.18) and younger age of female maturation (6.5-7.2 years) than had been assumed by Casey and Myers (1998). Results from the von Bertallanfy growth model yielded Linf =166.3 cm, k=0.14, and t_o=-1.2912. Given that the largest fish examined was 133.5 cm, it was felt that Linf might have been overestimated. When the model was rerun with an assumed Linf of 150 cm, the growth coefficient (k) increased to 0.18. Simon et al. (2002) had estimated an Lmat of 114 cm based on a small scale biological study in Div. 4W.

Parent et al. (2008) estimated the annual fecundity of this species from a single female that began laying purses in 2003. This fish produced 33, 69, 85, and 115 purses annually from 2003 to 2007. The length of the female in 2007 was 122 cm. Purses were laid throughout the year with a slight peak in the fall. Incubation time ranged from 343-494 days with a mean of 421 days. At birth, hatchlings averaged a total length of 19.3 cm and 32 g. Survivorship was good and, after 2 years in captivity, individuals ranged from 49 to 60 cm, which was comparable to an estimated length at 2 years old of 45-60 cm by Gedamke (2006). The water temperature at the Montreal Biodome was maintained at 10°C.

Overview of Canadian RV Surveys

Quebec Region, Div. 4RS, Subdiv. 3Pn

Barndoor skate were caught in only three of the 7,830 survey sets in the Div. 4RST, Subdiv. 3Pn (0.04%). Two fish were caught in the upper reaches of the Laurentian Channel in 1985. In 2005, a single fish measuring 114 cm in total length was captured in the same area. All fish were caught in greater than 200 m of water (Figure 5).

Gulf Region, Div. 4T

Barndoor skate were recorded in only eight of the 5,163 survey sets (0.15%). These fish were caught in 1972, 1974, 1979, 1984, 1987, 1988(2), and 1990. Length range was 36-138 cm of which four were mature (≥114 cm). All fish were caught along the edge of the Laurentian Channel at a depth range of 60-358 m (Figure 6).

Newfoundland and Labrador Region, Subarea 23

The spring RV survey is primarily confined to Subarea 3 with a few sets in Subarea 2. A total of 15,315 sets have been conducted since 1971. Only three barndoor skate were recorded in the entire time series. These were from 1974, 1976, and 1977. The depth of capture was 208, 241, and 338 m, respectively. Two of the fish were captured in Subdiv. 3Ps while the other was caught in Div. 3L (Figure 7).

The fall RV survey extends from the Davis Strait (Subarea 0) south to the Grand Banks (Divs. 3NO), and east to Div. 3M (outside Canadian waters). A total of 18,992 sets have been completed since 1977. Only five barndoor skate were recorded from this series. These fish were caught in 1996 (Div. 3M), 2000(3) (Div. 3O) , and 2001 (Div. 3L) at depths of 1040 m, 499 m (2), and 634 m, and 1174 m, respectively (Figure 7). The individual captured at 1,174 m represents the deepest confirmed record of barndoor skate from any Canadian RV database.

Maritimes Region

Summer Survey of the Scotian Shelf (Divs. 4VWX)

The summer RV Survey is the longest running survey series in the Maritimes region having been conducted annually in July since 1970. Out of the 6,783 sets completed during 1970–2008, only 86 sets or 1.3% captured barndoor skate.

The composite distribution pattern revealed a few areas of concentration, notably the western Scotian Shelf and the Gully (Figure 8). The distributional data was separated into two time periods, 1970-1992 and 1993-2008, to compare when the species was originally abundant to the most recent time period (Figure 8). During 1970-1992, barndoor skate were distributed across the entire shelf although some large sets were recorded near the Gully on the eastern Scotian Shelf and in Div. 4X (Figure 8). From 1993 to 2008, barndoor skate were concentrated in the southern half of Div. 4X and in the western portion of Div. 4W. No barndoor skate have been caught east of 62°W. The data was also disaggregated into juveniles (<114 cm) and adults (≥114 cm) (Figure 9), which revealed that juveniles had been caught throughout the survey area while adults were infrequently caught by the survey. Adults were primarily caught in Div. 4X in the Fundian Channel (Figure 9).

An examination of the mean numbers and weight per tow for Divs. 4VWX revealed low estimates from 1970-1980 that declined to zero by 1981 (Figure 10). The anomalous 1978 estimate point was driven primarily by catches near the Gully of 12 and 66 fish and a set in Georges Basin (strata 483) of 9 fish. These are the three largest sets in the series. Only 2 fish were captured on the entire shelf from 1981 to 1992. Beginning in 1993, barndoor skate began to reappear in Div. 4X and have continued to increase. The 2007 and 2008 estimates were the highest and third highest in the series in that area and they have subsequently begun to reappear in Div. 4W.

The length disaggregated abundance trends revealed that the survey primarily catches juveniles. Adults were only caught in 13 of the 39 years of the series although adult abundance appears to be increasing since 1998 (Figure 11).

Overall length frequencies were compared between 1970-1992 and 1993-2008 (Figure 12). Although the range of lengths caught by the survey has not changed significantly, in general, the size of animals caught from 1970-1993 tends to be smaller than those caught in the 1993-2008 period.

This information leads to the conclusion that recent trawl surveys captured only juvenile barndoor skate in significant quantities while adults were rarely captured. The abundance time series may better reflect some measure of recruitment variation.

Spring Survey of the Scotian Shelf (Div. 4VsW)

The annual survey of the eastern Scotian Shelf (4VsW) in March has only 2 records of barndoor skate out of 1,795 sets since the beginning of the series. In 2000, a fish measuring 37 cm was caught in 230 m of water near the Gully and in 2002, a second fish was caught in 130 m near the boundary with Div. 4X (Figure 13).

Winter Survey of Georges Bank (Div. 5Ze)

A total of 2,038 sets have been completed since 1986 with 158 or 7.8% containing barndoor skate. Barndoor skate were primarily distributed along the southern flank of Georges Bank from the Northeast Peak to the Great Southwest Channel (Figure 14) with small concentrations along the northern edge of the bank. There does not appear to be a break in distribution between the Canadian and USA sides of the bank. Abundance was predominately juveniles, which were distributed throughout the known distribution. Adults were primarily distributed on the southern peak of the bank (Figure 14).

Abundance trends have been produced for both the Canadian side of the bank (Subdiv. 5Zc) (Figure 15) and the entire bank (Div. 5Ze) (Figure 15). Given their continuous distribution on the bank, it makes little biological sense to provide trends for both areas, but it is required by COSEWIC to estimate abundance in Canadian waters.

An examination of the stratified mean number per tow from the Canadian side of the bank revealed estimates generally less than 0.1 per tow prior to 1998 (Figure 15). In 1998, abundance jumped to greater than 0.5 per tow. Abundance has generally decreased since 1998 except for the 2006 estimate, which was the highest in the series. The 2008 survey was conducted approximately one month later than normal due to weather and it is unknown how it might have affected the survey estimate.

When the entire bank (Div. 5Ze) was considered, overall abundance generally increased from the early 1990s to estimates greater than 0.5 per tow in 2007. The peak estimate of greater than 2 per tow was in 2003. The 2008 estimate was very low and a possible reason for the decline was conducted approximately one month later than normal due to weather (Figure 16).

The length disaggregated abundance trends for the entire bank (Div. 5Ze) and the Canadian zone only (Div. 5Zc) revealed that adults were only occasionally caught by the survey (Figures 17, 18).

Length range of barndoor skate caught by the survey revealed little difference between the Canadian zone (Div. 5Zc) and the entire bank (Div. 5Ze) with a range of 19-131 cm and a peak near 55 cm (Figures 19, 20)

Overview of USA RV Surveys, SubArea 56

A comparison of the seasonal surveys conducted by the USA revealed some small scale seasonal movement by barndoor skate. The fall survey indicated that the species may spread out somewhat onto the bank but there was no movement into the inshore region (NMFS, 2007)

(Figure 21). Distribution during the spring RV survey was similar to the Canadian 5Z survey in February (NMFS, 2007) (Figure 22).

The winter survey indicated that the centre of distribution is near the Nantucket Lightship at that time of year and this may involve some movement from Georges Bank (NMFS, 2007) (Figure 23). Given the concentration of abundance along the southern flank of the bank, it is possible that the species distribution continues into deeper waters and that the entire population was not sampled.

Distribution from the 1991-2006 scallop survey is also presented for completeness (NMFS, 2007) (Figure 23).

Abundance trends from both the spring and fall surveys are presented (Figure 24) but, given the area surveyed and the longer time series, the fall survey was examined in more detail. The fall series began in 1963 at which time barndoor skate abundance was high. By the late 1960s when the spring RV began, abundance had decreased to low levels and was reduced to near zero by the mid 1970s in both series. Barndoor skate began to reappear in the mid 1980s in both surveys; abundance recovered in the late 1990s to estimates observed in the late 1960s and have continued to increase in the 2000s. The mean abundance in the last four years of the fall survey was 57% of the mean of the first four years of the series. The abundance estimate from the spring RV survey in 2006 increased to values seen in the early 1960s, and the 2007 estimate is the highest in either series. An examination of the catch rate from the strata primarily in Canadian waters of the spring and fall RV surveys revealed little difference from the overall survey (Figure 25).

Due to use of chain sweeps with small cookies, the winter RV survey series has the highest catches of any USA survey (NMFS, 2007). In 2007, a total of 355 barndoor skate were caught, by far the highest number observed.

The abundance of barndoor skate from the fall RV survey was disaggregated by length into juveniles and adults, similar to the Canadian survey. Adults (≥114 cm) appeared to be more commonly caught in this survey than the Canadian survey for the same area and the percentage of adults in the catch appears to be increasing in the last seven years (Figure 26).

Length range and peak length of capture appeared to be similar to the Canadian survey for the same area (Figure 27). When the composite length frequency of the early abundance period was compared with the recent peak in abundance, it appears that there were smaller and larger fish being caught (Figure 27).

Using abundance of barndoor skate less than 40 cm from the fall RV survey as a proxy for recruitment (ages 0 and 1) revealed that recruitment has been generally high since 1999 (Figure 28) except for a catch of zero in 2004. There was a positive relationship between the number of adults (≥114 cm) and the number of age 0 fish the following year (lagged by one additional year to account for one year in the purse) (Figure 29). An interesting relationship was the one between the number of age 6 (105-113 cm) and the total number of adults (≥114 cm). The number of adults being produced in recent years is much higher than those seen in the 1960s (Figure 30).

Population Sizes and Trends

Estimates of minimum trawlable abundance were calculated by extrapolating RV survey catch per tow to the total number of trawlable units in a survey area. These estimates should be

considered minimum estimates given that catchability of the survey gear is much less than one. This is particularly the case for large skate species such as barndoor skate (see Edwards, 1968 discussion below). Minimum total population estimates were calculated from the research vessel surveys for Div. 5Z and Divs. 4VWX from the Canadian and USA surveys. These data are not provided for the other regions given the very low catch rates in those areas. Similarly, it was not possible to estimate minimum trawlable abundance from the industry surveys. Estimates are provided for juveniles and adults where possible. Given the sharp decrease in abundance to zero in the 1960s and 1970s, a long period of sporadic catches of barndoor skate in the 1980s, followed by recent increases, it was not felt to be appropriate to calculate decline rates over three generations (39 years). Instead, mean estimates of total abundance were calculated by generation (13 years) or natural break points in the data.

Trends in population levels were estimated using linear regression after log transformation. Concern has been expressed on the use of this method when the data series in question is complex and non-linear, so rates of increase are provided for only the most recent periods.

Edwards (1968), using cameras, noted that barndoor skate were particularly adept at avoiding capture by survey gear but did not provide an estimate of catchability. Harley et al. (2001) in their analysis of trawl survey catchability used observations by Edwards (1968) to estimate a catchability factor of 0.1 for barndoor skate.

Casey and Myers (1998) calculated total population abundance of barndoor skate from non-standard pre-1970 transect surveys. Transect survey data were converted into stratified abundance estimates. Subsequently, half of the data collected before 1970 were multiplied by 2.08 assuming that catches during night were higher and most of the sets in that period were during the day. The catchability factor of 0.1 for other skates suggested by Edwards (1968) were then applied to further adjust all estimates. This resulted in all catch rates being multiplied by a factor of 6.7 prior to 1970.

Although we have been able to confirm that barndoor skate were caught in the pre-1970s surveys, the lack of consistent survey design, the use of unknown gear types, and uncertainty in whether fishing was conducted over a 24-hour period suggests that it is inappropriate to calculate total population estimates prior to the advent of the standard surveys in 1971 for Subdiv. 3Ps, Divs. 4VW, and Div. 4X. An examination of the DFO pre-1970s database in 2002 revealed that mean catch per tow estimates of barndoor skate in Div. 4X during 1962-1969 and in Divs. 4VW during 1958-1969 were much higher than estimates from the subsequent standard stratified surveys in the same areas and estimates declined rapidly to near zero by the start of the standard survey (Simon et al., 2002). Survey estimates occurred in each of the above years as opposed to only three annual observations by Casey and Myers (1998) on the Scotian Shelf for the same time period. It is unclear why only a subset of the data was presented by Casey and Myers (1998). An attempt to replicate their observations in Subdiv 3Ps was unsuccessful but it was noted that in some of the years when they assumed only daytime fishing, operations continued around the clock and thus, the multiplication factor applied would have been inappropriate.

Georges Bank, Div. 5Z

Total abundance estimates from the Canadian RV survey for Div. 5Ze and Subdiv. 5Zc were calculated for both juveniles and adults. Total abundance of all size classes in Div. 5Ze averaged 52,000 fish during 1987-1995. During 1996-2008 (one generation), abundance averaged 622,000 juveniles and 11,000 adults (Figure 18). On the Canadian side of the bank

(Subdiv. 5Zc), total abundance of all sizes averaged 15,000 individuals during 1987-1995. Since 1996, average abundance has been 43,000 juveniles and 2,300 adults (Figure 17).

The annual rate of increase from 1986 to 2008 for Div. 5Ze was 6.0% (Figure 31) but there was no clear trend in the data over this time period for the Canadian portion of Georges Bank alone (Figure 32). If only the last generation is considered (1996-2008), then there is an annual rate of decline of 18.3% in the Canadian zone.

Inter-annual changes in total abundance for the USA fall and spring RV surveys (Figures 24 and 26) appear to be significantly less than those seen in the Canadian survey on Georges Bank, especially within the Canadian zone (Figures 17 and 18). These differences in inter-annual abundance may not be biologically feasible and suggest that this indicator may not be suitable to track changes in population abundance in such a small geographic area. The international boundary is an arbitrary delimiter of a larger ecosystem and the Canadian zone may be too small an area to track overall population changes in this ecosystem. Area occupied, which has less inter-annual variability than total abundance, may be a better indicator of changes in the population.

Annual mean minimum abundance from the USA fall RV survey (Divs. 4X5ZY6) during 1963-1975 (one generation) was 1.1 million juveniles and 62,000 adults. During 1976-1994 (19 years), mean abundance was 54,000 juveniles and 2,800 adults. During 1995-2007 (one generation), the estimate was 79,700 juveniles and 112,000 adults. The average of the first four years of this survey was 3.2 million fish while the average of the last four years was 1.7 million fish or 53% of the earlier period (Figure 26).

The annual rate of increase from 1995 to 2007 for the fall RV survey was 11.4% for all size classes (Figure 33). The trend in total abundance from the spring RV survey was similar to the fall RV survey for the same area (Figure 24) and the annual rate of increase from 1995 to 2007 (one generation) for this survey was 14% for all size classes (Figure 34). Given the very low abundance of adults and the unknown catchability by length, separate abundance estimates for juveniles and adults were not calculated.

Abundance trends from a subset of the USA RV survey strata which approximate the portion of the survey in Canadian waters were similar to those observed for the entire survey area, but precise total abundance estimates for the Canadian portion are not available because many of the USA strata are bisected by the international boundary (Figure 25).

Scotian Shelf, Divs. 4VWX

Data pertaining to the Scotian Shelf were grouped into three generation periods (13 years): 1970-1982, 1983-1995, and 1996-2008. The average annual number of juveniles was 152,000, 15,000, and 118,000 for each of these three time periods, respectively. The number of adults for these same time periods was 11,000, 0, and 39,000. The 1978 survey year was included in the calculations for the 1970 to 1982 period even though the survey contained three sets with the highest number of individuals (76, 12, and 8) from the entire summer RV survey series and might be considered anomalous. If this year is excluded, the mean number of juveniles decreases to 38,000 from 152,000 while the average number of adults increases slightly to 12,000 (Figure 11).

The annual rate of increase for the Scotian Shelf from 1996 to 2008 (one generation) was 8.9% for all size classes (Figure 35).

Canadian Industry/Science Surveys

Sentinel Survey of the Eastern Scotian Shelf (Div. 4VsW Longline)

Barndoor skate catches were concentrated along the western boundary of the survey area (or central Scotian Shelf) between Emerald Basin and Emerald Bank and southward to the edge of the shelf (Figure 36). This area is almost entirely covered by the 4 core strata that were sampled throughout the series. Total number of survey sets was 2,027 with 176 reporting barndoor skate (8.7%). The stratified mean catch (number and weight per tow) from the core strata of the Div. 4VsW Sentinel Survey increased from less than one fish per tow to seven fish per tow during 1996-2007 (Figure 37). The annual rate of increase corresponding to this time period was 11.8% (Figure 38). No length frequencies are available from this survey.

Halibut Survey of the Scotian Shelf and Southern Grand Banks (Divs. 3MNOP4VWX)

Distribution from the fixed portion of the halibut longline survey revealed that barndoor skate were primarily caught in Div. 4X and the western part of Div. 4W (Figure 39). This later area was similar to the distribution seen in the 4VsW Sentinel Survey. As well, fish were found along the southern edge of the Scotian Shelf and the Grand Banks (Figure 39). Total number of sets in the fixed station surveys was 1,994 with 269 occurrences of barndoors (13.8%). The index fishery portion of the survey fished in waters that were often deeper than the fixed phase, and barndoor skate were identified in these waters as far east as the tail of the Grand Banks (Figure 40).

Stratified mean catch (kg) per tow in the entire survey area increased from 2 kg to 17 kg per tow from 1998 to 2007 (Figure 41). The annual rate of increase was 7.4% (Figure 42).

An examination of catch rates from both the fixed and commercial index sets by binned depth ranges and area suggests that barndoor skate are caught at a wide depth range (Figures 43 and 44). A closer examination of the data revealed catches as deep as 730 m in the fixed station survey (Figure 43) and 700 m in the commercial index (Figure 44). In both surveys, null sets extended out beyond 900 m. Figure 45 displays catch by depth from both the fixed station and commercial index sets in more detail.

Length frequencies were collected from both the fixed and commercial index portions of the survey, but unfortunately, prior to 2008, they were not consistently collected annually so stratified estimates could not be generated. The fixed station length frequency ranged from 58-129 cm with a peak between 100 and 125 cm (Figure 46). The commercial index length frequency ranged from 52-163 cm peaking near 100 cm (Figure 46). The fish in this survey are close to the largest ever seen. The 2008 length frequencies are available but should be considered preliminary until editing of the survey is complete (Figure 47). Data was binned by area and depth. No significant differences were found in the length frequencies greater than or less than 200m in Divs. 4VWX from the fixed stations survey (Figure 47). Data from commercial index stations in Divs. 3NOP suggested that the largest fish were found in this area (Figure 47).

Total mortality (Z) estimates were calculated on the descending limb of the 1998 commercial index length frequency using growth parameters developed by Gedamke (2006). The resulting Z was 0.23 (Figure 48).

ITQ Survey of the Southwestern Scotian Shelf (Div. 4X Otter trawl)

This survey has been conducted each July since 1995 using four industry trawlers equipped with rockhopper foot gear. Skate were not separated by species until 1996. A total of 2,523 sets have been completed with barndoor skate occurring in 90 or 3.6% of the sets. Barndoor skate were generally captured in the deep waters off German and Browns Bank (Figure 49). The mean catch per tow from the ITQ survey increased from less than 0.1 kg to 0.7 kg per tow in Div. 4X from 1996 to 2006. In 2007 and 2008, abundance fell to values observed during the first two years of the survey (Figure 50). The annual rate of increase for the ITQ Survey series (1996-2008) was 3.2% (Figure 51).

Area of Occupancy

In Divs. 4VWX, average area of occupancy, based on the summer RV survey, from 1970 to 1980 on the Scotian Shelf was approximately 1,700 km^2. From 1981 to 1992, barndoor skate were only caught in two of the survey years. Since 1993, this index has increased from less than 1,000 km^2 to a peak of 7,850 km^2 in 2007. The 2008 estimate of 6,140 km^2 is the second highest in the series (Figure 52).

On the Canadian portion of Georges Bank (Subdiv. 5Zc), the area of occupancy averaged below 120 nm^2 from 1987 to 1997, increased to an average of 325 nm^2 from 1998 to 2006, and fell to pre-1998 estimates in 2007 and 2008 (Figure 52). If the entire bank (Div. 5Ze) is considered, then prior to 1994, stratified area occupied averaged less than 300 nm^2. From 1994 to 2007, the mean stratified estimate was 2,300 nm^2, with a peak of 4,100 nm^2 in 1999. The 2008 estimate was 356 nm^2 (Figure 52).

The total area surveyed by the USA is 174,868 km^2. In 2007, the area occupied by barndoor skate was 20,323 km^2.

Because stratified area occupied was not available for the Sentinel and Halibut surveys, the percentage of sets in which barndoor skate occurred in those surveys was used. The trend was similar to stratified area occupied in the RV surveys. Percentage of sets occupied in the Sentinel Survey increased from less than 20% within the core area to greater than 40% of the sets (Figure 53). In the Halibut Fixed Station Survey, skates occurred in approximately 10% of the sets from 1998 to 2004. During 2005 to 2007, this increased to 18-32% of the sets (Figure 54).

Barndoor Skate have not been encountered in the deepwater sets (365-732 m) of the Maritimes Region since they were included in the survey in the mid 1990s. During that same period, a small number of barndoor skate have been caught at those depths in the NL and Labrador Region. The use of the Campelen Trawl may have increased their catchability in that region. In both the Maritimes and Newfoundland and Labrador regions, barndoor skate have been caught in the 365-732 m depth range by the halibut survey since the mid-1990s. The total area of the deepwater strata in Divs. 4VWX is 4,459 km^2, which would be approximately the same area as the deep water strata in Divs. 3NOP.

The total area of the Flemish Cap (Div. 3M) shallower than 700 m is 59,740 km^2. It is unknown how much of the bank is occupied by barndoor skate.

LOESS Curves

All Canadian, USA, and industry/science research survey results were summarized in Figure 55 by adjusting their individual catch rate series so they could be put on the same scale. A loess

curve fit using a 35 bin size was used to smooth the data. Most surveys show similar patterns of increase although the ITQ and Canadian side of Div. 5Z indicate a recent decrease.

Habitat Associations

Ecosystem Considerations

Food habits data by size classes were compared between data collected on the Scotian Shelf in the 1960s with the recent (1999-2003) information summarized by Gedamke (2006) on Georges Bank. The diet of barndoor skate is dominated by fish and crustraceans with the proportions of these items changing with body size.

Small barndoor skate (<70 cm) are predominantly bottom feeders consuming primarily shrimp on the Scotian Shelf and crabs on Georges Bank. Large barndoor skate (>70 cm) consume primarily fish in both areas with large proportions of silver hake (*Merluccius bilinearis*) and haddock (*Melanogrammus aeglefinus*) on the Scotian Shelf. On Georges Bank, they consume sculpins (*Myoxocephalus* sp.), red hake (*Urophycis chuss*), and ocean pout (*Marozoarces americanus*). In both areas they consume herring (*Clupea harengus*).

The trends in abundance of the prey fish species from these studies were compared with the abundance of barndoor skate for their respective areas. Overall, the abundance trends for prey species of barndoor skate were not consistent with the abundance trends of barndoor skate, suggesting that the availability of these prey species was not associated with the recent increase in barndoor skate.

An in-depth analysis of the above information is contained in Appendix A.

Essential Habitat

Composite distribution patterns by length group from the Scotian Shelf and Georges Bank did not provide sufficient information to point to critical concentrations of this species. Juveniles and adults on Georges Bank appeared to occupy the same geographic area on both the Canadian and USA sides of the bank. On the Scotian Shelf juveniles appeared to be spread across the entire shelf, but adults were more concentrated in the Fundian Channel. When only fish less than 40 cm (a proxy for ages 0 and 1) were considered, their distribution on Georges Bank (Figure 56) was similar to the other size ranges while on the Scotian Shelf (Figure 56), this size category has only been observed four times since 1970. Gedamke (2006) considered barndoor skate not fully recruited to the trawl gear until they reached 55 cm. It was not possible to locate any positional records on barndoor skate purse observations. As stated before, a single female with almost complete purses was sampled from the Sentinel Survey in Div. 4W but no positional data was available. As part of the Scotian Shelf survey in Divs. 4VWX, the lead author requested that all skate purses be retained for the last 3 years, but no barndoor skate purses have been observed in that time, even though they are quite distinctive (Vladykov, 1936).

Length frequency data from the halibut survey prior to 2008 suggests that adults are more common at depths greater than the RV surveys but they also catch adults in significant quantities at shallower depths. The 2008 data once edited, may provide the detailed information necessary to advance this analysis.

Temperature and Depth Preferences

Barndoor skate are widespread from 38-351 m in Div. 5Z but have been reported from the shoreline to 750 m (Packer et al., 2003). Temperature range from trawl surveys from the Gulf of Maine to Cape Hatteras was 3-18°C with a reported peak of 20 °C off Cape Hatteras. Salinity preferences ranged from 32- 36 ppt in the same areas. No differences were found between adults or juveniles (Packer et al., 2003).

On the Scotian Shelf, barndoor skate have been reported from 24-375 m and were primarily caught in 50-150 m. Off Newfoundland, they have been recorded as deep as 1174 m. Temperature range on the Scotian Shelf based on the Canadian summer RV survey is 2-11 °C with barndoor skate being most abundant at 3-9 °C (Figure 57). Temperature range on Georges Bank based on the Canadian winter RV survey is 3-13 °C with barndoor skate being most abundant at 4-6 °C (Figure 58) In the Gulf of St. Lawrence barndoor skate have been recorded at a temperature as low as 1.2 °C (Packer et al., 2003).

Barndoor skate have been found on all types of bottom substrate on the continental shelf to depths of 750 m (Scott and Scott, 1988).

Re-examination of Observer Reports from Commercial Fisheries

As a result of the concerns raised in 2002 of species identification by observers, the 3,247 records of barndoor skate from the Newfoundland and Labrador observer database were re-examined. Criteria were developed to determine whether species identification could be confirmed and applied against the dataset. As a result, only 309 of the original records were considered valid and, of these, only 209 occurrences came from the Newfoundland and Labrador Region. The remaining 100 records were from the other Atlantic regions. These criteria may have resulted in the elimination of valid records of barndoor skate but the resulting dataset is believed to better reflect the distribution of the species.

The revised distribution of barndoor skate is shown in Figure 59. This indicated that species was widespread in Div. 3OP especially near the edges of the banks. Most of these records were from 1978- 1982. Since 1998, there have been only 21 records of the species, 19 of which have come from the Flemish Cap. By comparison, there has being a single record in 1996 of barndoor skate in this area from the RV survey.

Another potential species identification problem was discovered when white and spinytail skate distributions were examined from the Maritimes observer database. Barndoor skate were thought to have been potentially misidentified as these two species in 2J3KL given their large size and pointed snout. Both species were described by Scott and Scott (1988) as having northerly distributions and white skate were found at depths greater than 1000 m. An examination of the RV surveys in Div. 5Z and Divs. 4VWX revealed only two records of spinytail skate on the shelf and no white skate in either survey. Observers from the Maritimes Region reported white skate from Georges Bank, the tail of the Grand Banks and the Davis Strait (Figure 60), while spinytail skate were broadly distributed on the Georges Bank, the Scotian Shelf, north to the Davis Strait (Figure 61). Given their relative absence in the RV surveys on the Maritimes region, it is likely that most of these reports from Div. 5Z and Divs. 4VWX are misidentifications and it is possible that many of these are barndoor skate. This will require further investigation.

Threats

Information on potential threats to barndoor skate is limited. Given their large size, it is likely that adults may only be preyed upon by large sharks and marine mammals. An examination of the DFO Maritimes stomach data base revealed only one instance of barndoor skate being consumed by another fish (cod). Predation on egg cases by gastropods has been observed for skate species in other areas (Cox et al., 1999) but no data exist for barndoor skate. The only potential threat for which there are quantitative data is mortality from groundfish fisheries. The survivorship of barndoor skate captured as bycatch and discarded is unknown.

Casey and Myers (1998) suggested that barndoor skate populations were reduced to extremely low levels because they were taken as bycatch in other major fisheries but provided no supporting data. Pre-COSEWIC documents (Simon et al., 2004; Kulka et al., 2006) on winter skate and smooth skate have attempted to estimate removals by these fisheries since 1977 by using limited observer reports. To fill in the gaps in the data, the percentage of skate by species from the research vessel surveys was sometimes used in the Gulf of St. Lawrence and on the Scotian Shelf. Both of these methods rely on having enough records of speciated skate to prorate unspeciated skate observations by species. Given the very few reports of barndoor skate since the observer program began in 1977 and the above mentioned species ID issues, it was felt that neither method could be used to estimate long-term removals from fisheries over the entire range of the species.

To address this issue, the total reported landings of all groundfish species by all countries were summarized annually from Div. 5Z, 4X, 4VW, and Subdiv. 3Ps in which barndoor skate were reported to be near extinction by Casey and Myers (1998). These landings were intended to be a proxy for effort, which was not available for all areas or years. Landings were then compared with the RV survey trends for each division separately where possible. No attempt was made to extend the RV data series prior to the beginning of the standard surveys.

On Georges Bank (Div. 5Ze), total removals of all groundfish was almost 100,000 t in 1960. Removals increased to greater than 600,000 t by 1965 and remained greater than 200,000 t until the mid 1970s. By 1977 and the extension of jurisdiction by the USA and Canada to 200 miles, total landings had decreased to 125,000 t and have generally been below 100,000 t since 1985 (Figure 62). The precipitous decline in abundance of barndoor skate in this area was coincident with the sharp increase in landings for the area in the mid 1960s. In 1994, an area closed to groundfish dragging was created on the USA side of the international boundary but was reopened to limited scallop fishing in 1999 (Gedamke, 2006). The effect of this closure is unknown but will provide a measure of protection near the centre of distribution on the bank. There has not been any significant change in total landings since the mid 1990s when the RV abundance trend increased sharply (Figure 62).

In Div. 4X, the spike in landings noted in Div. 5Z was not evident. Landings prior to 1994 were generally between 60,000 and 90,000 t. In 1994, landings decreased sharply to 45,000 t and have continued to decrease to approximately 20,000 t in 2007 (Figure 62). Seasonal closures exist to protect spawning haddock on Brown's Bank but no large permanent closures exist in this area. Unlike Div. 5Z, the decline in skate abundance in the mid 1970s does not appear to be coincident with a significant change in landings.

In Divs. 4VW, landings have been variable ranging from 150,000 t in the early 1960s to greater than 300,000 t in the early 1970s. Landings averaged approximately 150,000 t in the 1980s. A haddock nursery area was created in 1987 in Div. 4W to provide protection for juvenile fish – draggers were restricted from this area in 1987 and longline gear was excluded in 1994. Since

1994, directed fisheries for cod and haddock have been closed in Divs. 4VW and total landings have been below 20,000 t (Figure 63). However, there have been no restrictions on the use of scallop gear within the haddock nursery area. There appears to be no relationship between fishing effort (landings) and the decline in skate abundance in this area. The recent increases in barndoor skate abundance in the summer RV survey (since 2000) are occurring at a time of very low fishing effort.

In Subdiv. 3Ps, total landings have been variable ranging from approximately 60,000 t to 115,000 t in the 1960s. Landings peaked at around 120,000 t in 1970 and fell to approximately 45,000 t by the early 1980s. Landings since the mid 1990s have ranged between 5,000 and 35,000 t (Figure 63). The decline in barndoor skate abundance in this area during the 1960s that was noted by Casey and Myers (1998) is coincident with the highest reported landings for the series, but it is unclear whether these landings were the cause of the decline in barndoor skate abundance in this area.

Although it was not possible to estimate total removals for the entire range of the species, an examination of observer reports was used to estimate total annual bycatch since 1986 from more restricted areas (Div. 5Zc and Div. 4X) where the species is relatively abundant (Table 1; unpublished DFO Working Paper by Purchase et al., 2004). There is a high degree of uncertainty in these estimates due to low observer coverage. Where fisheries were not listed, it means there was no observer coverage or there was no recorded bycatch. Survival of discarded barndoor skate is unknown but the mortality of other skate species was estimated to be greater than 50% in the Gulf of St. Lawrence (Benoît, 2006).

In Subdiv. 5Zc, bycatch estimates were calculated for the yellowtail flounder and the combined cod, haddock, and pollock otter trawl (OT) fisheries. As well, estimates were available from the combined cod and haddock longline (LL) fishery and the scallop fishery. The highest rate of barndoor skate bycatch occurred in the yellowtail flounder fishery (1.05%) while the lowest rate occurred in the scallop fishery (0.07%) within this area. Total removals were highest in the scallop fishery (15 to 40 t). Total annual bycatch estimates from all fisheries combined for Subdiv. 5Zc ranged 26-100 t from 1986 to 2007 (Table 1).

In Div. 4X, the highest recorded bycatch rate was from the combined cod and haddock LL fishery (0.65%) with the lowest reported rate from the redfish fishery (0.05%). Total annual bycatch from all fisheries combined ranged 25-115 t from 1986 to 2007 (Table 1).

Relative F's were calculated using the total bycatch estimates in Div. 5Zc and Div. 4X and the appropriate biomass estimates from the summer and Georges Bank RV surveys. These reveal that in Div.5Zc, relative F was generally below 0.2 except for 1993, 2001, and 2003 when relative F was near or above 0.4 (Figure 64). In Div. 4X, relative F was above 0.2 in 1994 and 1997. Since 1999, the estimate has been very low (Figure 64).

An examination of reported landings of skate since the 1960s, using a combination of NAFO and Canadian fisheries statistics, revealed high levels of skate removals from Divs. 4VWX and Div. 5Z from the late 1960s to the mid 1970s primarily by foreign countries (Figure 65). None of these landings have been identified to species. It has been suggested that these landings may actually have been other groundfish species that were misreported as skate (Simon and Frank, 1996). Since 1994, skate landings have primarily come from the Canadian directed skate fisheries. On the Scotian Shelf (Subdiv. 4Vs, Div. 4W), the directed fishery focused on winter skate with a small bycatch of thorny skate. Skate removals increased to 2000 t, declined to near zero by the mid 2000s and the fishery has been closed since 2005 (Figure 65). Reported removals in Subdiv. 3Ps of all skate species generally increased from the mid 1960s peaking in

the late 1980s at 1,700 t. Landings reduced to near zero by the early 1990s. A directed fishery for thorny skate (Kulka et al., 2004) began in 1994. Landings peaked at 1,900 t in 1995 and have averaged 1,300 t since 1995 (Figure 65). In both directed fisheries, reports of barndoor skate have been negligible. There has been anecdotal information from DFO port samplers in southwest Nova Scotia that a small number of barndoor skate have been landed as bycatch with other species of skate from Georges Bank since 2000.

DISCUSSION/CONCLUSIONS

Barndoor skate was relatively more common in the 1950s and 1960s in comparison to later decades. They were sporadically encountered throughout the 1970s, nearly absent during the 1980s, and have increased in abundance since the mid-1990s. Recent abundance is near to or has exceeded the estimated abundance seen in the early periods throughout the central/western Scotian Shelf/Gulf of Maine area. Research vessel trawl surveys on Georges Bank, conducted by NMFS, have shown similar recent increases in barndoor skate abundance from all their surveys (Northeast Fisheries Science Center, 2007). Length frequency data from the RV surveys indicated that most individuals captured are juveniles.

There appear to be some persistent areas of concentration, i.e. those associated with Georges Bank/ Fundian Channel region, in the vicinity of Browns Bank, and the central and slope waters of the Scotian Shelf. Concentrations that were evident early in data series but are not evident now include the eastern Scotian Shelf (Divs. 4VW) and Subdiv. 3Ps. Recent reports indicate that barndoor skate have been captured in deep water extending to depths beyond 1000 m.

It was apparent from the industry/science surveys that barndoor skate were consistently captured at depths/locations beyond the standard research vessel surveys and include the southwestern slope waters of the Grand Banks. Maximum depth observed is near 700 m. Length composition of barndoor skate from these surveys revealed a wide range of sizes, indicative of both juvenile and adult fish.

A reanalysis of observation commercial fisheries data suggests that barndoor skate are not common north of Div 3L as previously reported. It is unknown if the concentration observed on the Flemish Cap is real, a separate DU, or simply an artifact of a lack of sampling between the tail of the Grand Banks and Div. 3M.

A review of life history characteristics revealed that the length at 50% maturity is in excess of 112 cm for both male and female barndoor skate combined. Age at 50% maturity is close to 7 yrs for females. As well, fecundity is about 100 purses per year, which is double that reported by Casey and Myers (1998). These characteristics indicate that barndoor skate are likely more resilient to overfishing than previously thought (Frisk et al., 2002; Dulvy and Reynolds, 2002).

Collectively, these data suggest that barndoor skate abundance has increased to near historical levels in the centre of their distribution and that it is increasing in the east. Whether or not this will ultimately result in repopulation of the eastern Scotian Shelf and the Grand Banks is unknown, but the pattern of increase suggests that the species is not at risk. Nonetheless, given the declines that occurred in the past, the abundance of barndoor skate should be closely monitored and caution applied in its management.

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TABLES

Table 1.Estimated bycatch of barndoor skate in Subdiv. 5Zc and Div. 4X based on fisheries that were observed to catch barndoor skate in those areas.

Fishery, 5Z Cdn	Yellowtail OT	CHP OT	CH LL	Scallop	Total Bycatch
Bycatch rate(%)	1.05	0.12	0.80	0.07	
1986	0.1	12.2	21.6	27.2	61.0
1987	0.0	15.2	34.1	39.5	88.7
1988	0.1	17.3	40.0	25.2	82.5
1989	0.0	5.7	42.4	27.2	75.3
1990	0.0	13.6	48.4	30.3	92.3
1991	0.1	13.9	48.1	33.7	95.8
1992	0.1	12.3	46.9	35.7	95.0
1993	1.4	12.7	26.9	36.0	77.0
1994	13.7	7.0	23.2	29.1	73.0
1995	4.1	3.1	7.4	11.5	26.0
1996	4.4	5.3	15.2	17.4	42.3
1997	8.4	4.7	16.3	24.7	54.1
1998	12.2	5.0	14.6	23.2	55.0
1999	20.7	4.7	14.1	21.5	61.1
2000	29.5	6.5	15.3	39.6	90.9
2001	30.3	8.3	21.6	39.9	100.2
2002	27.6	8.0	17.6	38.6	91.8
2003	21.7	7.9	19.9	35.9	85.4
2004	1.0	12.0	21.3	21.6	55.9
2005	0.3	16.8	21.4	15.6	54.2
2006	0.2	13.6	19.8	23.8	57.3
2007	0.1	13.0	19.9	25.6	58.6

OT=otter trawl *LL=longline*

Fishery, 4X	Redfish OT	CHP OT	CH LL	Halibut LL	Total Bycatch
Bycatch rate(%)	0.05	0.07	0.65	0.52	
1986	2.7	20.8	64.0	2.2	89.8
1987	2.3	21.6	67.0	2.0	93.0
1988	1.6	20.9	66.0	2.6	91.2
1989	1.0	17.6	53.1	1.9	73.5
1990	1.0	14.8	74.0	1.7	91.5
1991	0.8	22.5	89.8	1.3	114.5
1992	1.1	19.8	93.1	1.3	115.2
1993	2.4	12.5	51.9	1.3	68.2
1994	2.5	8.0	39.6	1.6	51.7
1995	2.3	7.2	32.6	1.0	43.0
1996	1.8	8.5	34.9	1.3	46.4
1997	2.7	10.7	36.7	1.5	51.6
1998	2.7	11.1	35.3	1.0	50.1
1999	2.1	6.7	28.6	1.0	38.4
2000	2.2	6.0	30.7	1.0	40.0
2001	2.0	7.7	27.8	1.2	38.7
2002	2.3	8.2	27.2	1.4	39.2
2003	1.5	9.4	25.6	1.5	37.9
2004	1.0	8.2	15.5	1.5	26.2
2005	1.5	7.5	14.3	1.7	25.1
2006	1.3	4.8	19.9	2.4	28.4
2007	1.4	7.1	22.5	2.0	33.0

FIGURES

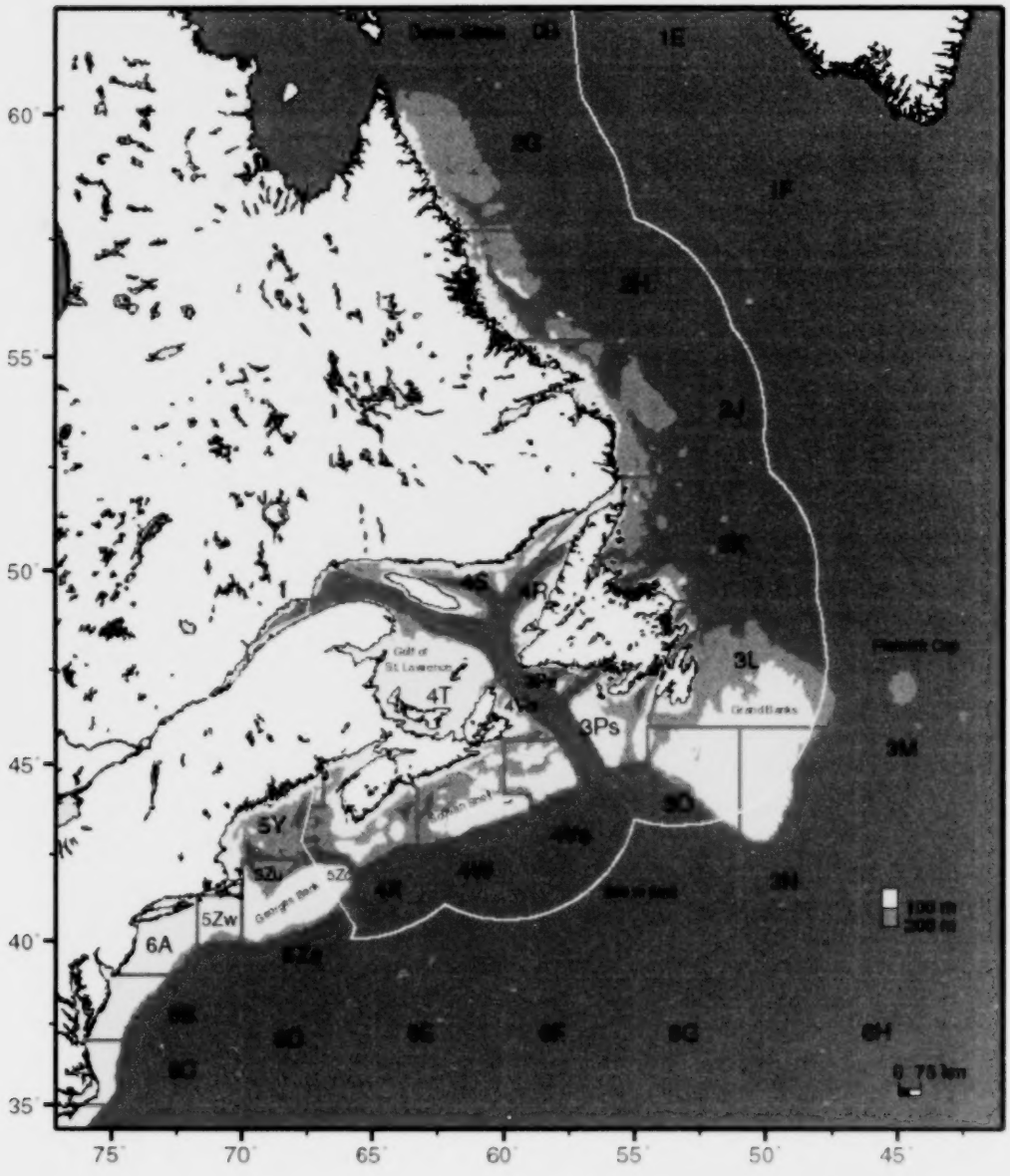


Figure 1. Geographic display of the areas and NAFO Divisions mentioned in this document.

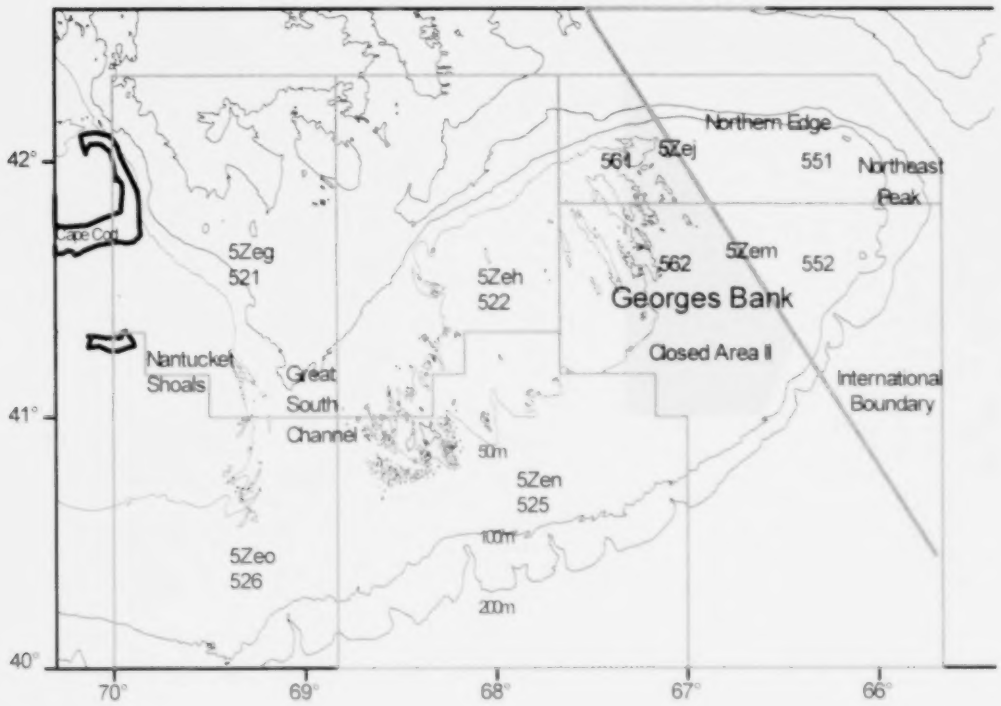


Figure 2. Geographic display of Georges Bank showing Closed Area II from where Gedamke (2006) developed the biological parameters used in this document.

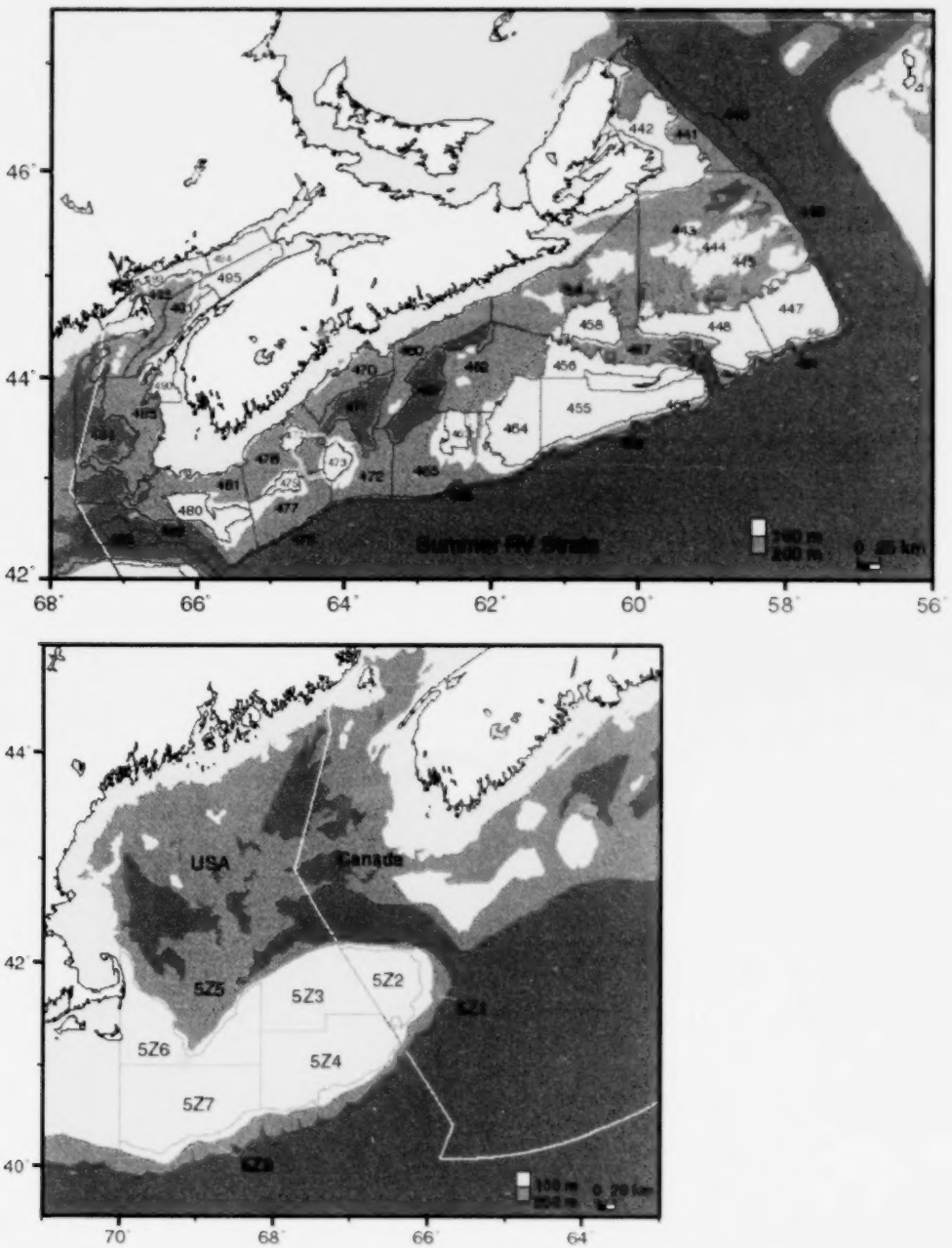


Figure 3. Canadian research survey strata used in the analysis of the Scotian Shelf (summer, 1970-present) (top panel) and Georges Bank (winter, 1986-present) (bottom panel). The deepwater strata added in 1995 to the southern edge of the Scotian Shelf are not shown.

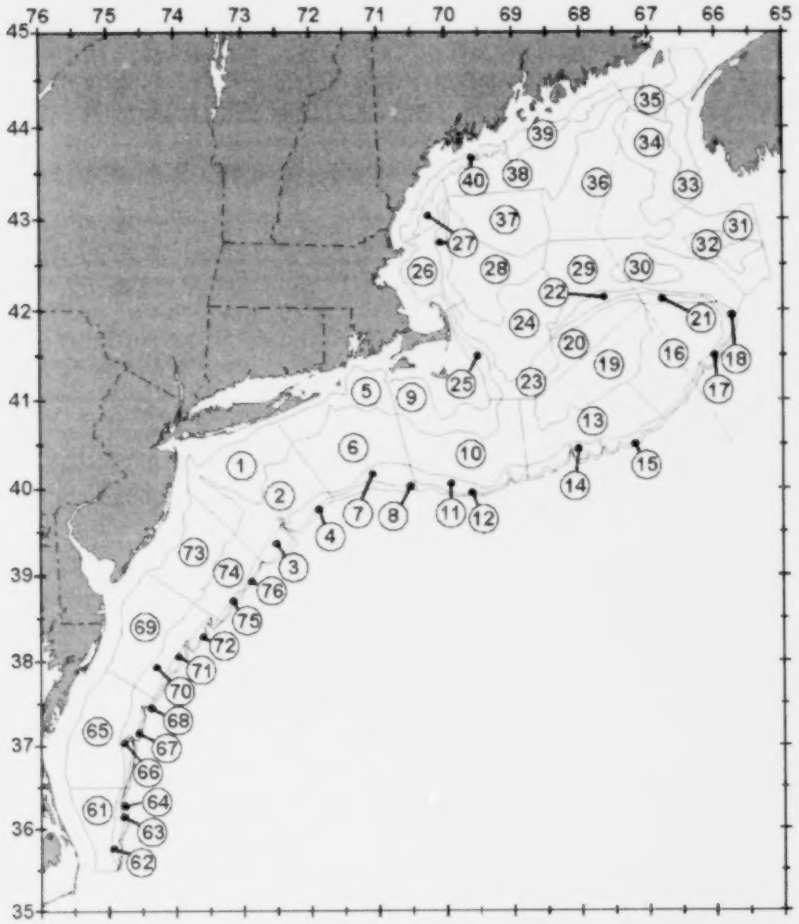


Figure 1. Strata sampled on NEFSC offshore bottom trawl surveys. Depths range from 27 to > 200 meters.

Figure 4. Research vessel strata (1963-present) used in the analysis of the spring, fall, and winter surveys of the USA. Note that many of these strata extend into Canadian waters.

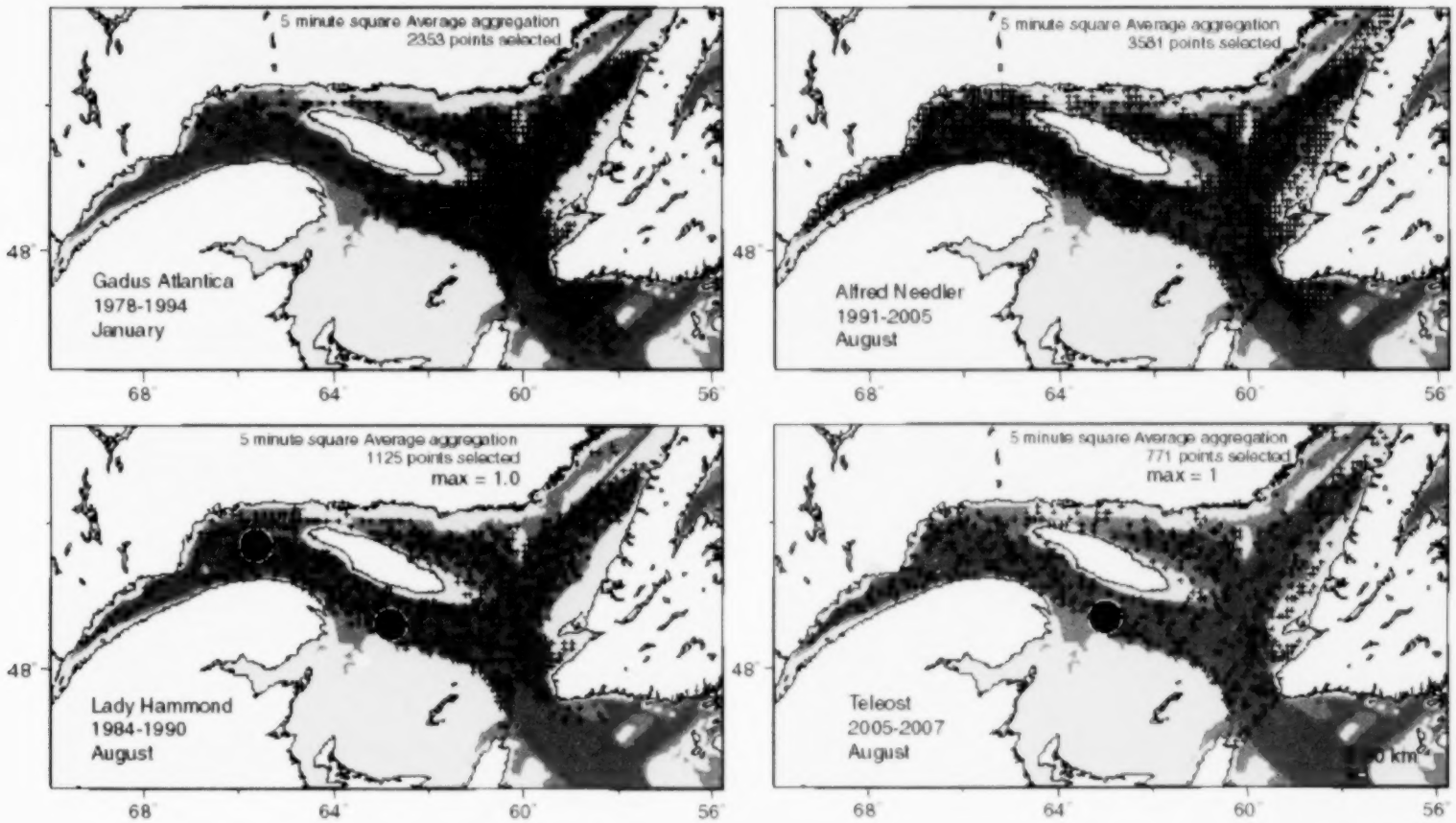


Figure 5. Distribution of barndoor skate from the northern Gulf of St. Lawrence (Div. 4RS, Subdiv. 3Pn) research vessel surveys. Barndoor skate have been caught in only 3 of 7,830 survey sets.

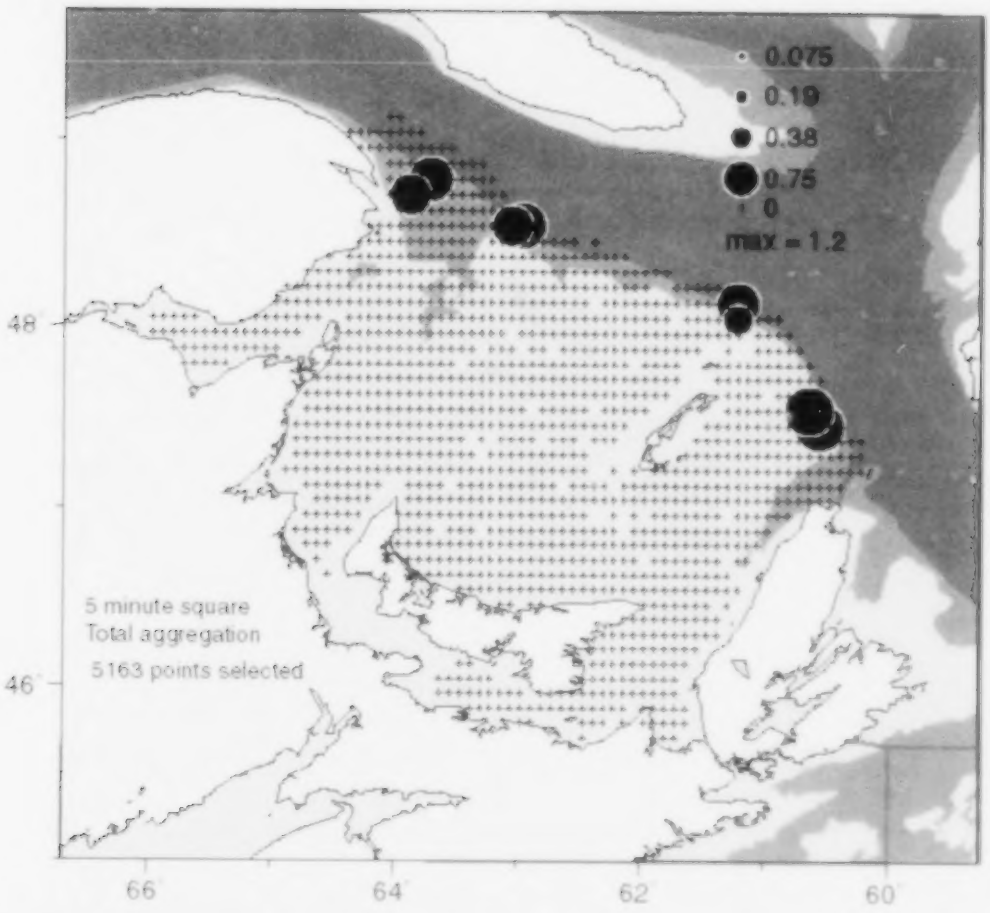


Figure 6. Distribution of barndoor skate from the fall DFO RV survey in Div.4T, 1971-2007. A total of 8 barndoor skate have been caught in this series.

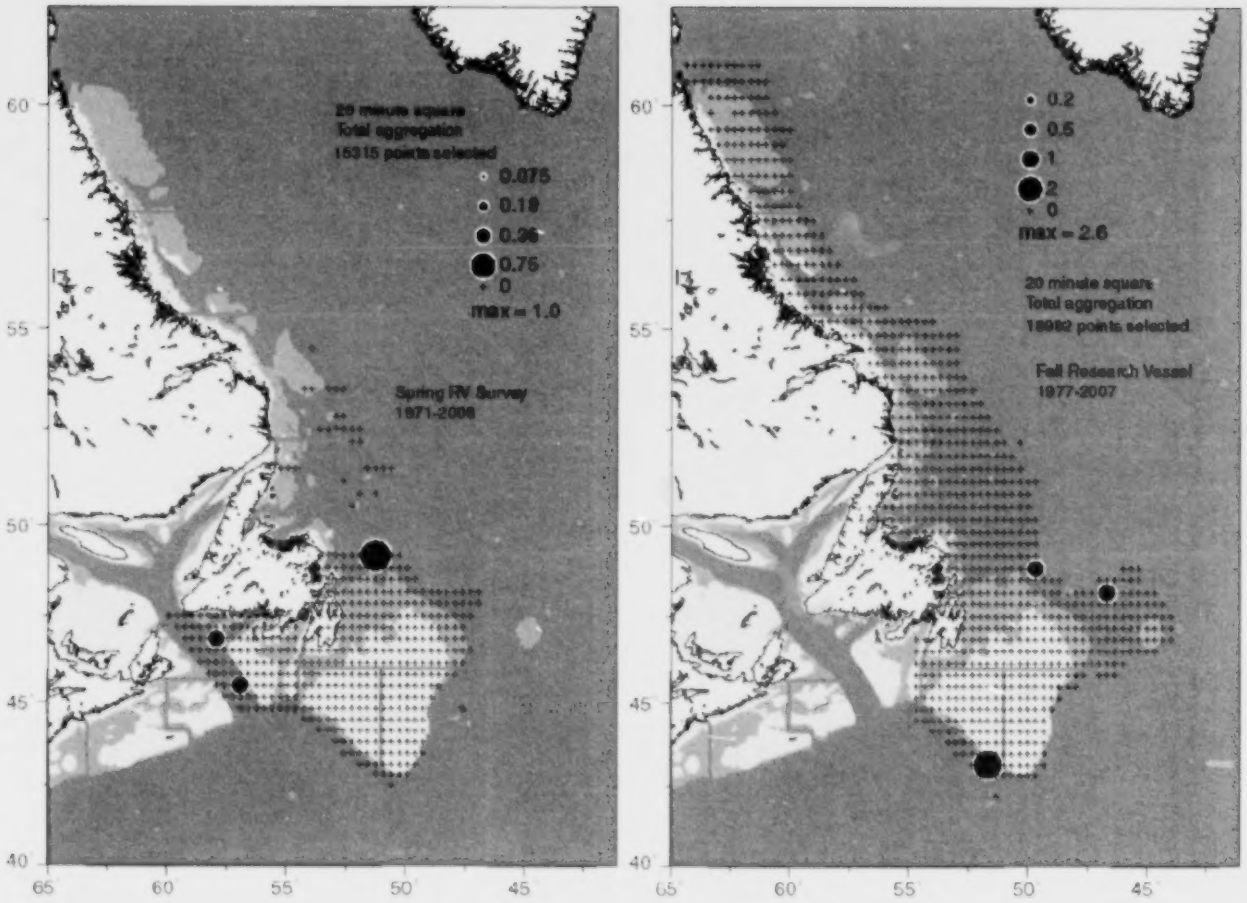


Figure 7. Distribution of barndoor skate from the spring (1971-2008) and fall (1977-2007) RV surveys in the Newfoundland and Labrador Region. In recent years, the fall survey has extended into deeper waters and Campelen trawl gear has been used. A total of 8 fish were captured in over 34,000 sets.

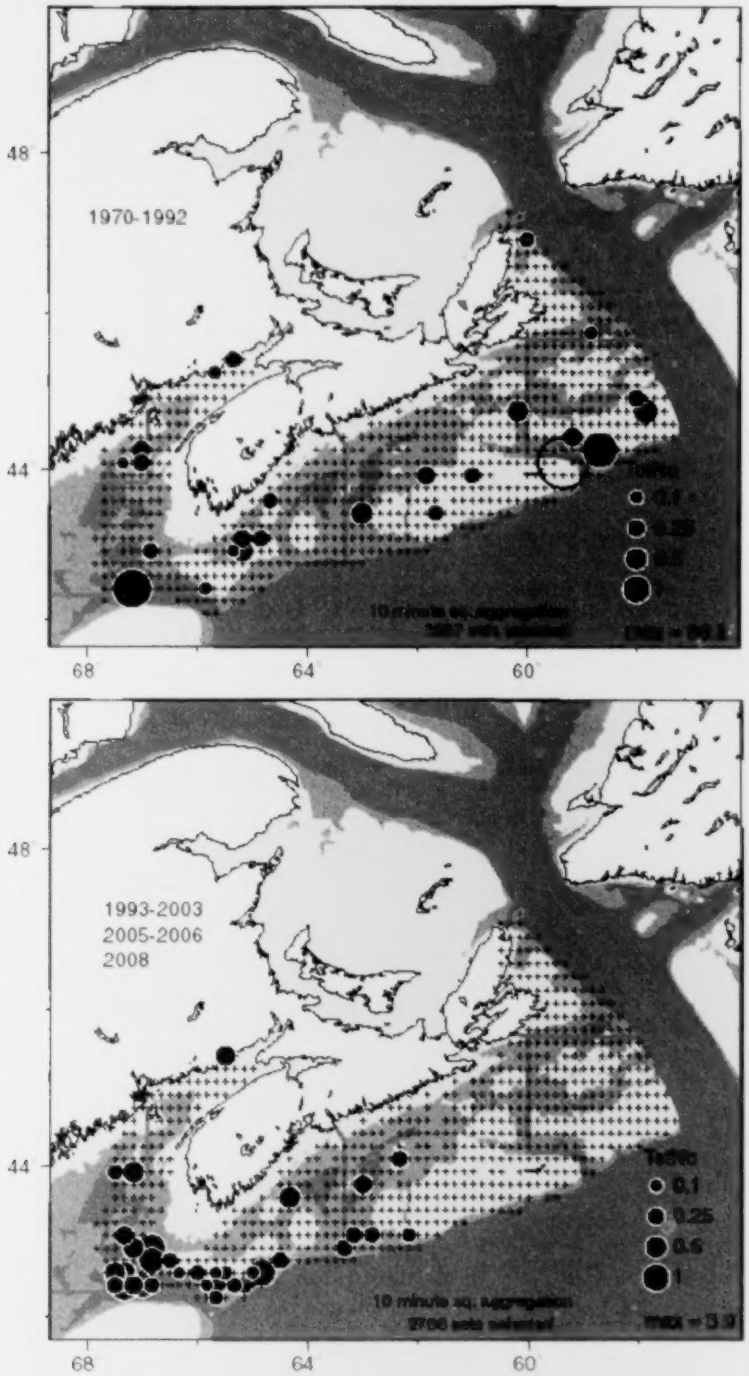


Figure 8. Distribution of barndoor skate on the Scotian Shelf as indicated by the summer RV survey from 1970-1992 and 1993-2008.

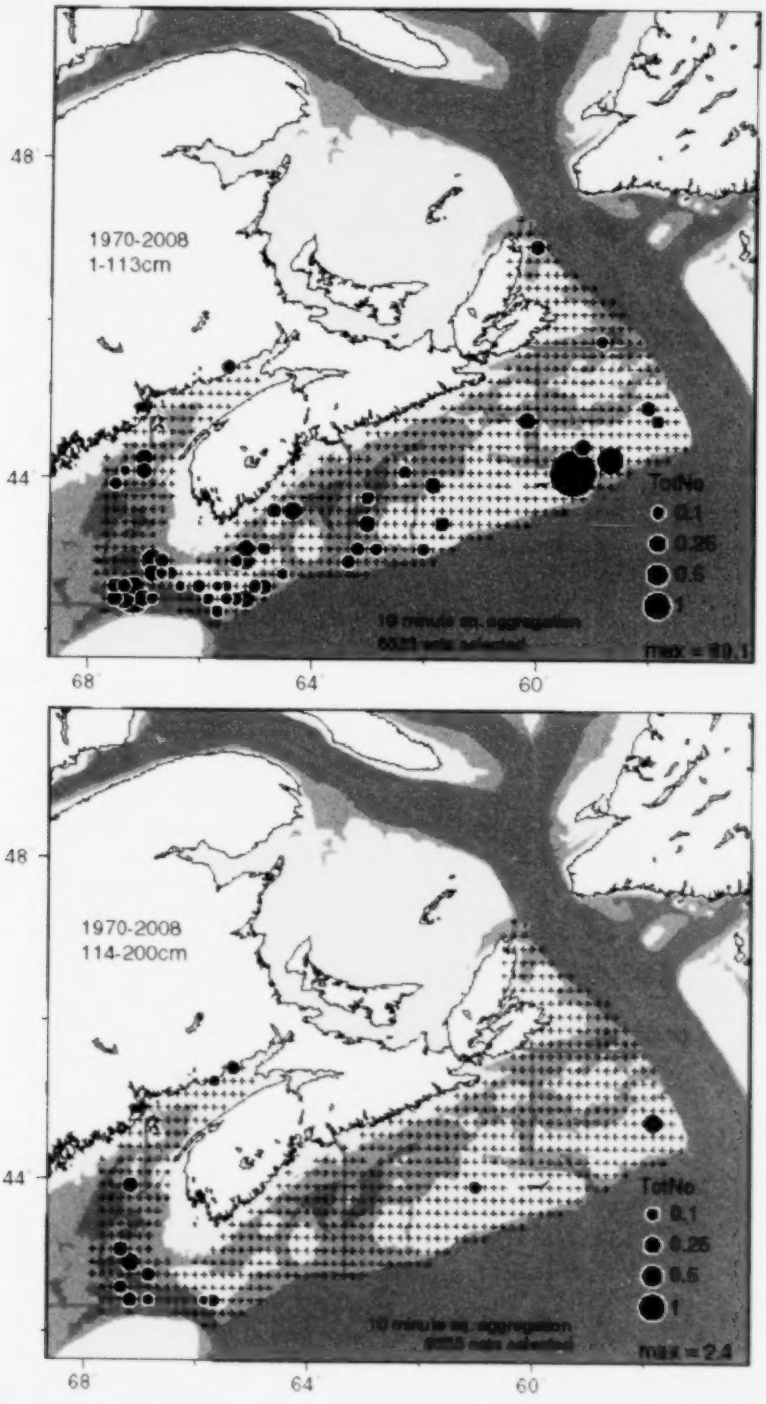


Figure 9. Distribution of juvenile (<114 cm) and adult (≥114 cm) barndoor skate on the Scotian Shelf as indicated by the summer RV survey, 1970-2008.

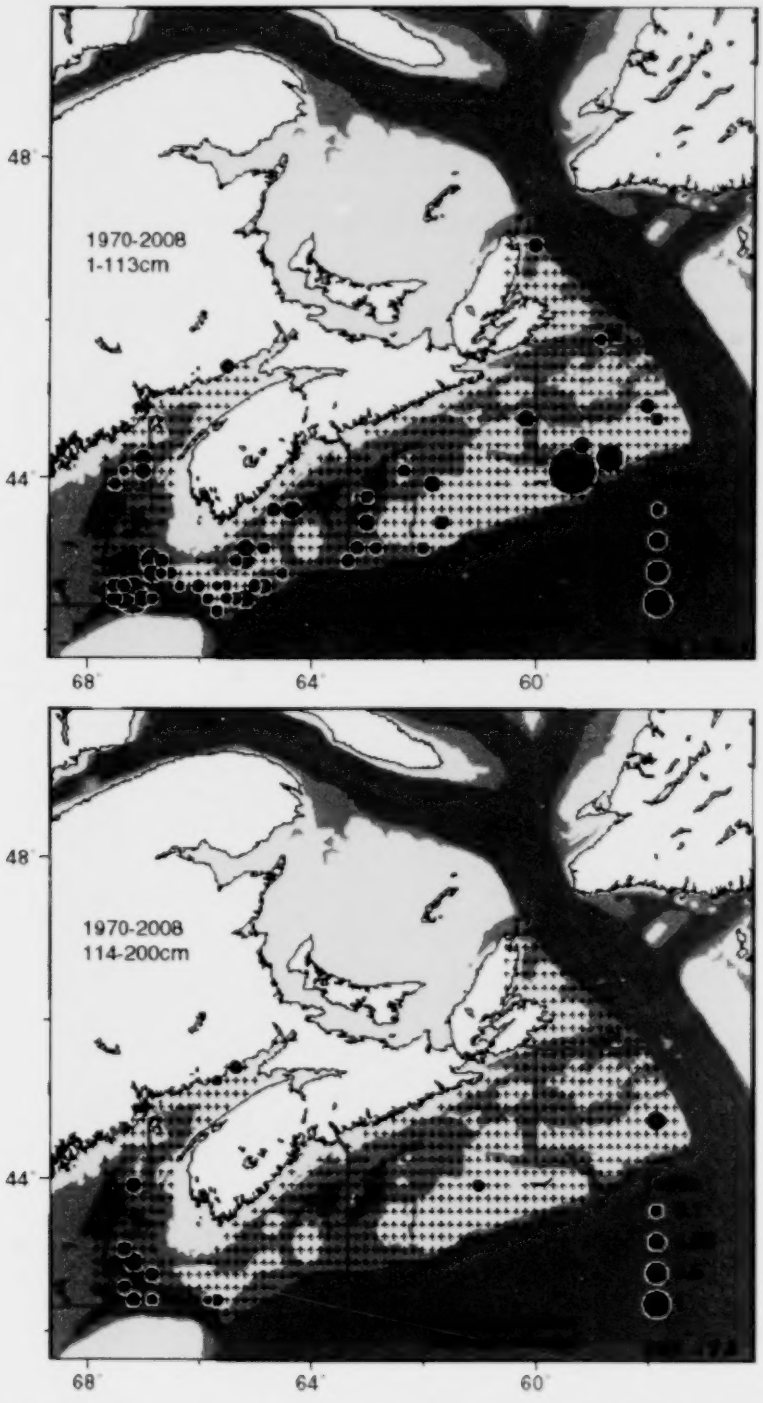


Figure 9. Distribution of juvenile (<114 cm) and adult (≥114 cm) barndoor skate on the Scotian Shelf as indicated by the summer RV survey, 1970-2008.

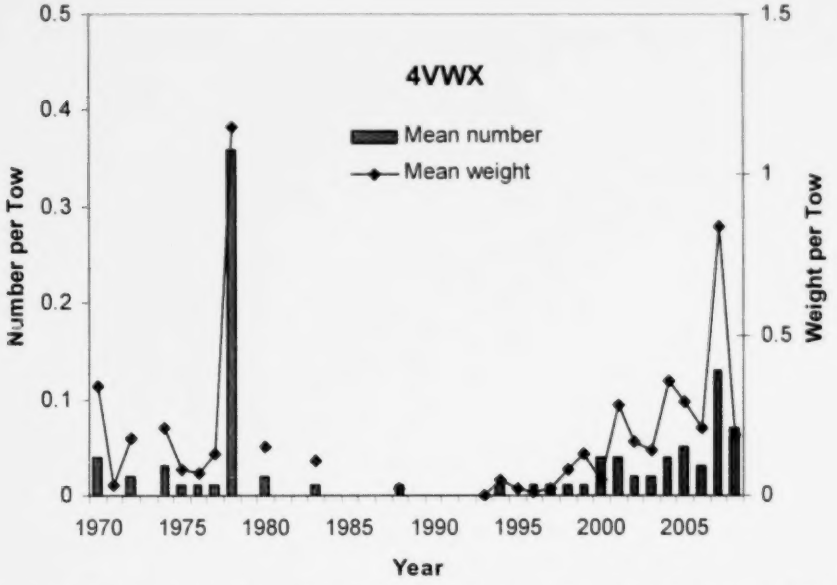


Figure 10. Stratified mean number and weight (kg) per tow from the summer RV survey in Div. 4VWX during 1970-2008.

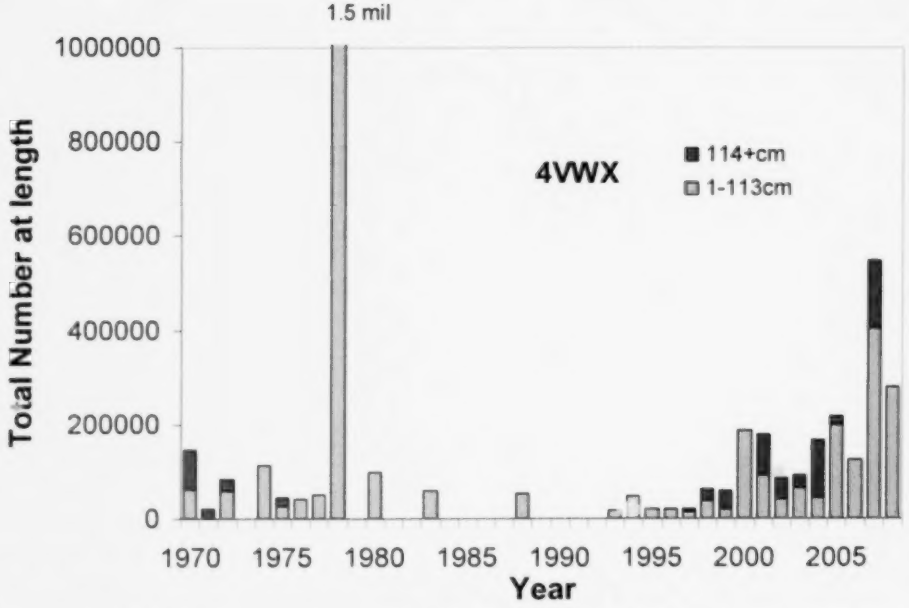


Figure 11. Abundance trends (total number) for juveniles (1-113 cm) and adults (≥114 cm) from the summer RV survey in Div. 4VWX.

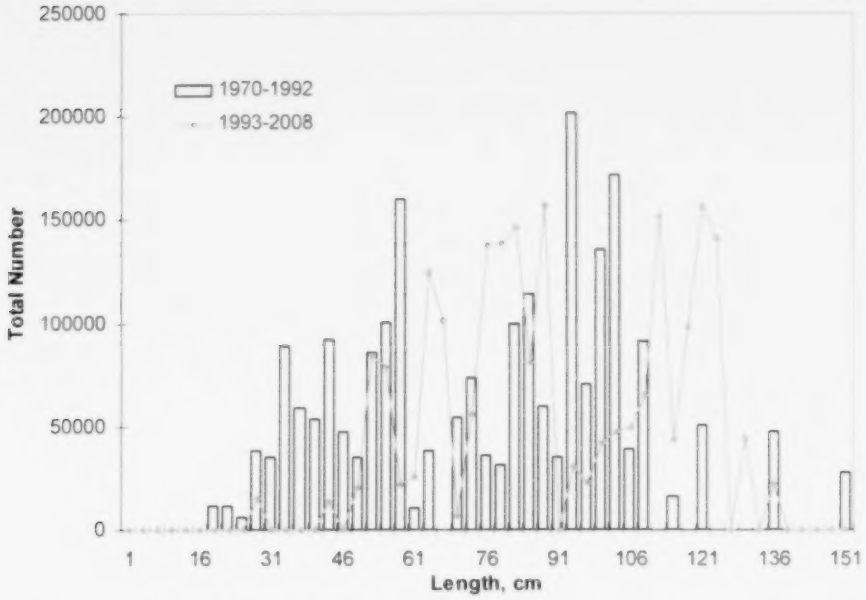


Figure 12. Cumulative length frequencies from the summer RV survey on the Scotian Shelf (Div. 4VWX) during 1970-1992 and 1993-2008.

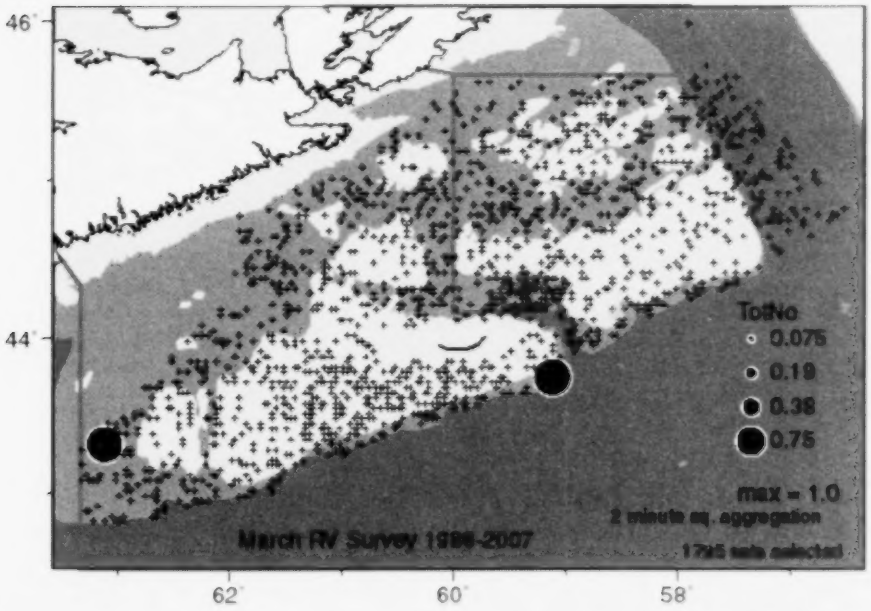


Figure 13. Distribution of barndoor skate as indicated by the spring RV survey in Div. 4VsW from 1986-2007.

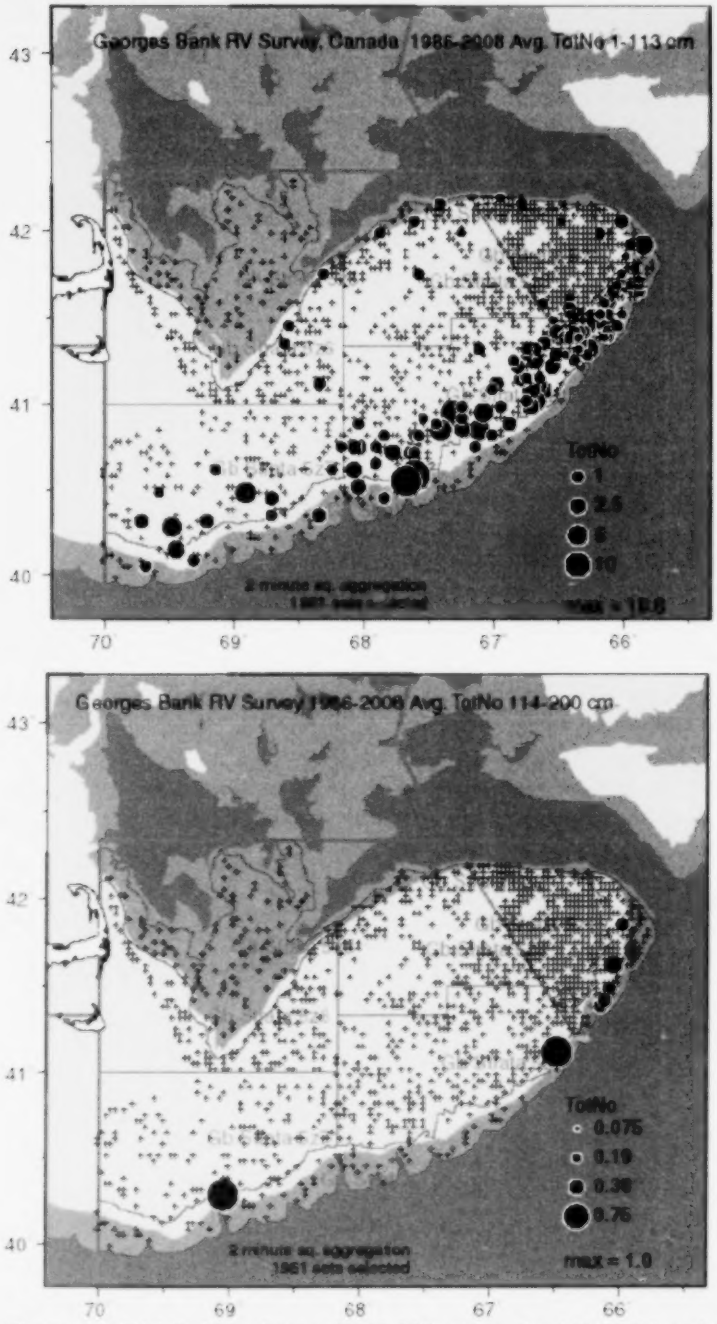


Figure 14. Distribution of juvenile (1-113 cm) and adult (≥114 cm) barndoor skate as indicated by the Georges Bank RV survey, 1986-2008.

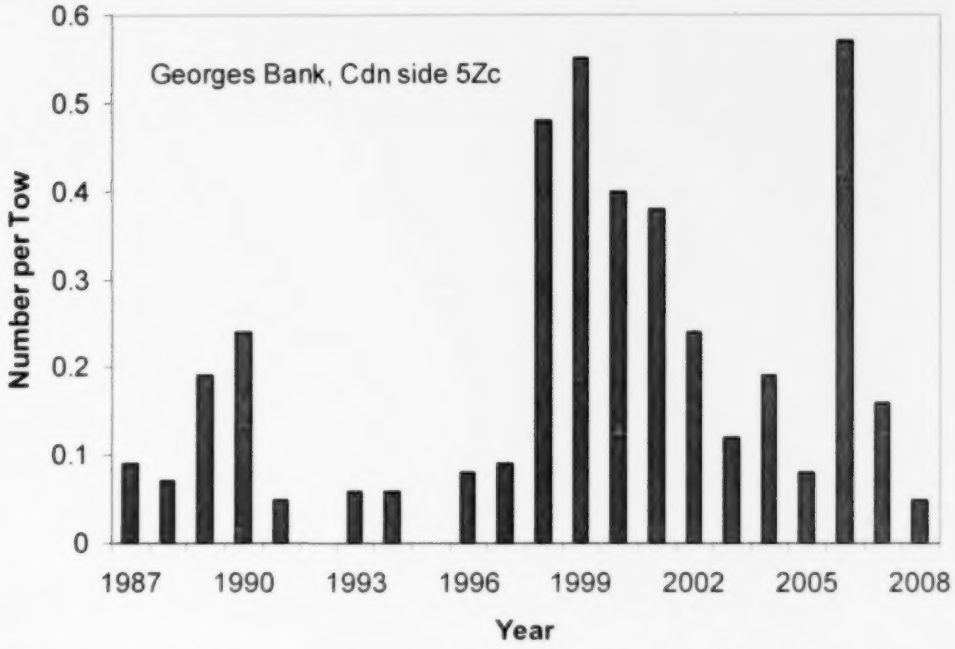


Figure 15. Stratified mean number per tow of barndoor skate from the Georges Bank RV survey, Canadian side only (Subdiv. 5Zc).

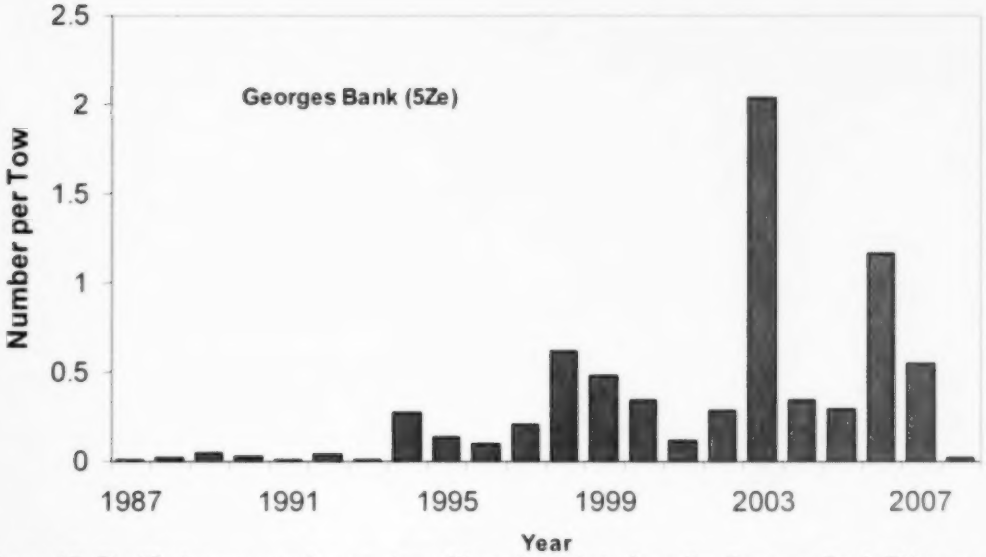


Figure 16. Stratified mean number per tow of barndoor skate from the Georges Bank RV survey, entire bank (Div. 5Ze).

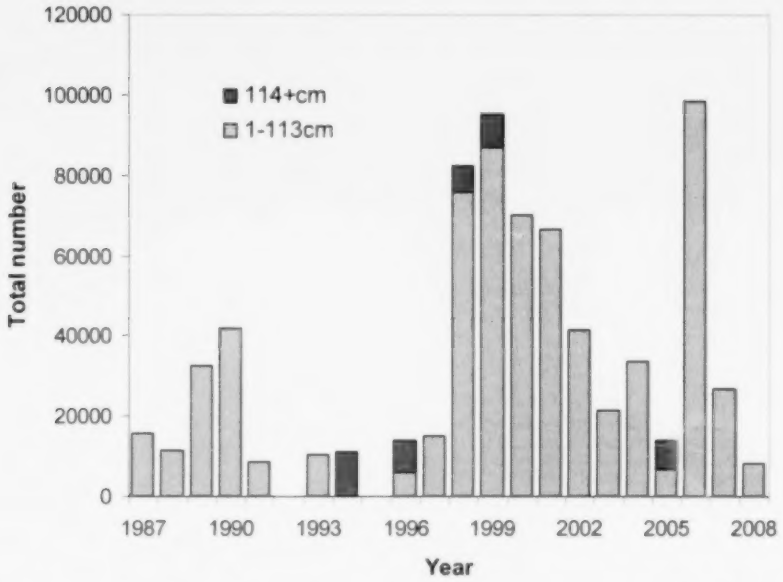


Figure 17. Stratified total number of barndoor skate caught on the Canadian side of Georges Bank, Subdiv. 5Zc, during the Georges Bank RV survey.

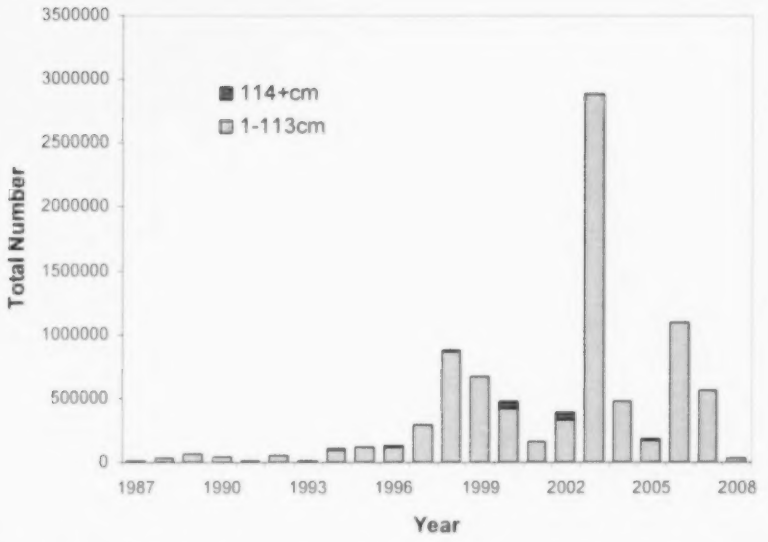


Figure 18. Stratified total number of barndoor skate caught on Georges Bank, Div. 5Ze, during the Georges Bank RV survey.

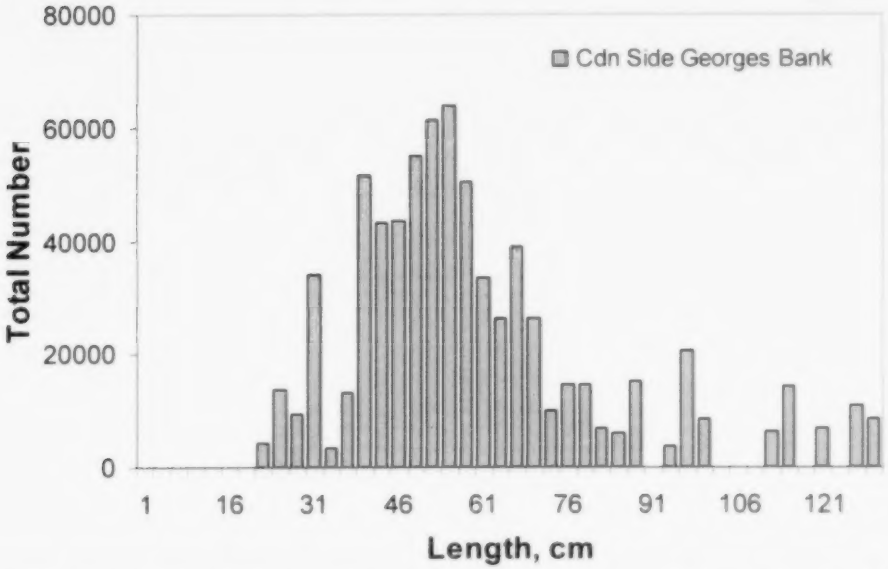


Figure 19.Total number at length caught in Subdiv. 5Zc, Canadian zone, during the Georges Bank RV survey, 1987-2008.

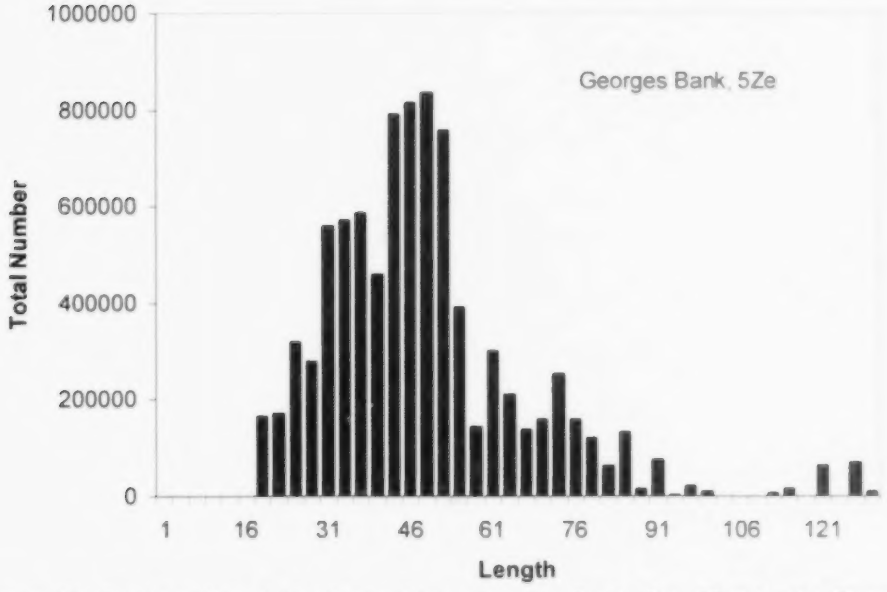
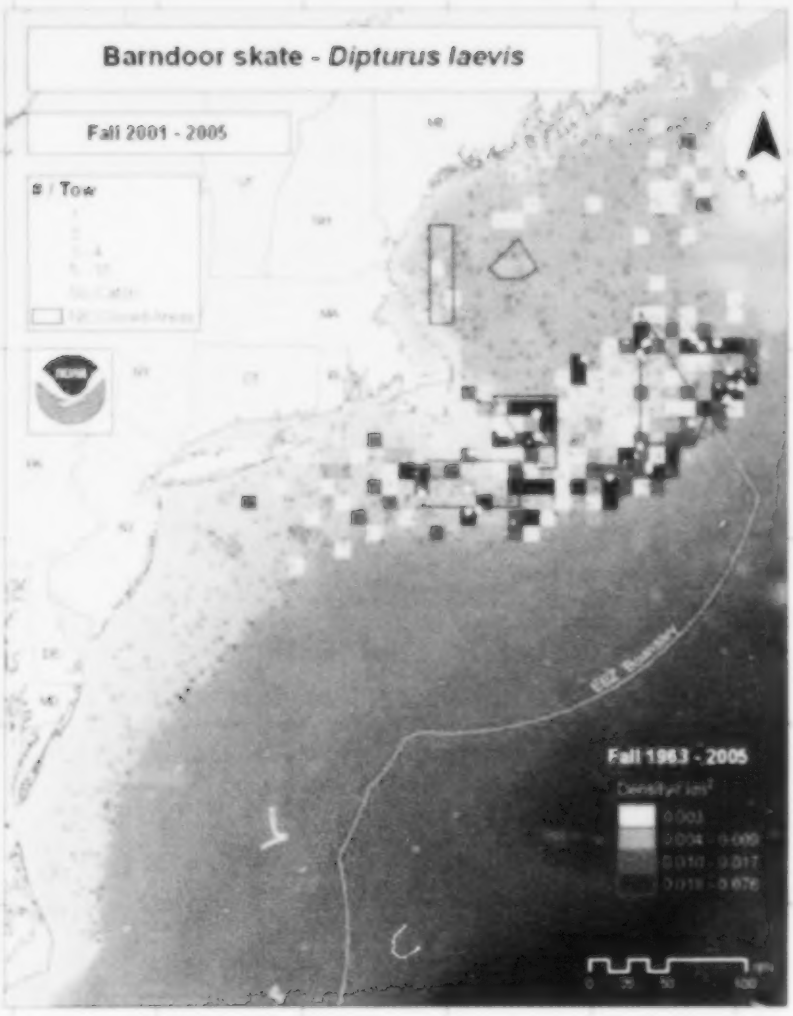


Figure 20. Total number at length caught on Georges Bank (Div. 5Ze) by the Canadian RV survey, 1987-2008.



Relative species abundance and distribution from NEFSC bottom trawl survey by time block and relative species density for the full time series

Figure 21. Distribution of barndoor skate as indicated by the USA fall RV survey, 2001-2005 (NFSC, 2007).

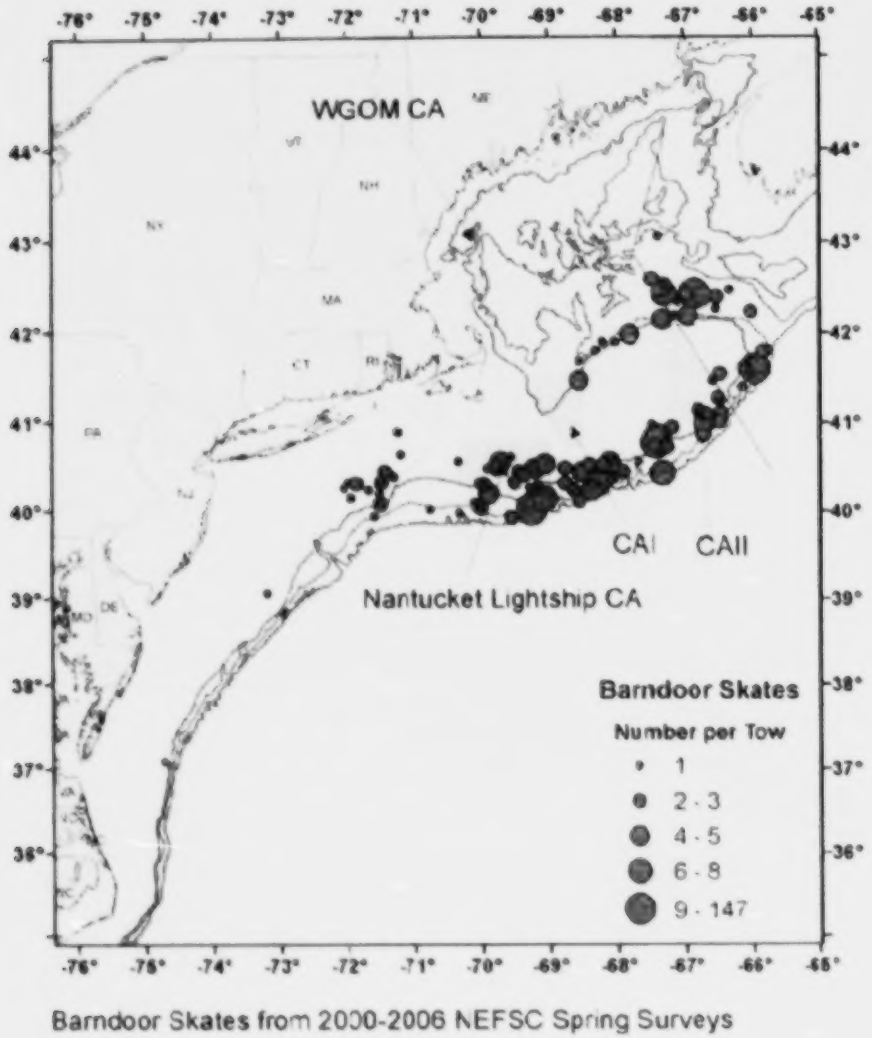


Figure 22. Distribution of barndoor skate as indicated by the USA spring RV survey, 2000-2006 (NFSC, 2007).

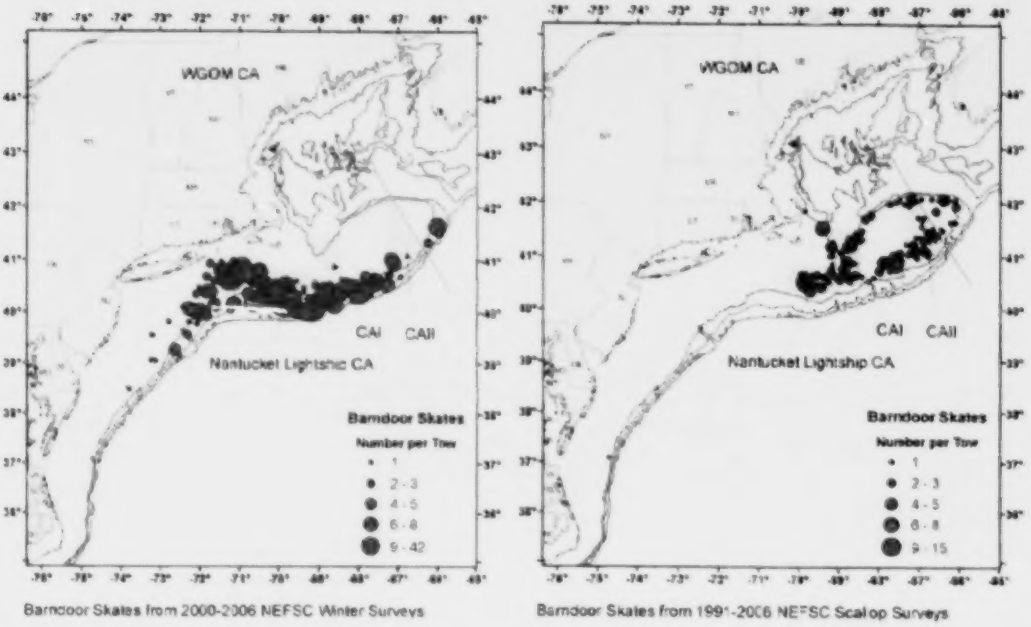


Figure 23. Distribution of barndoor skate as indicated by the USA winter RV and scallop surveys (NFSC, 2007).

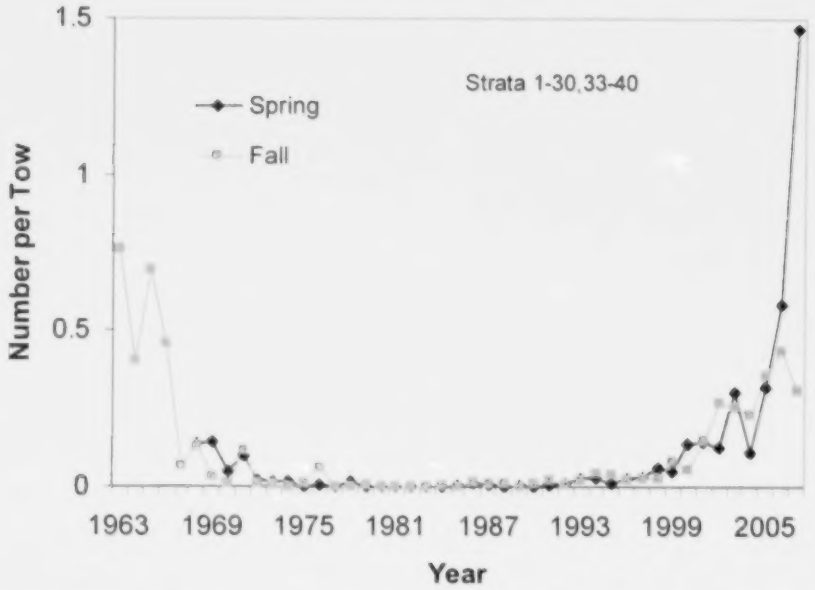


Figure 24. Abundance (number per tow) of barndoor skate in strata 1-30, 33-40 from the USA spring and fall RV surveys.

Figure 25. Abundance (number per tow) of barndoor skate in strata that are predominately in the Canadian zone from the USA spring and fall RV surveys. Note that some of the strata straddle the EEZ line.

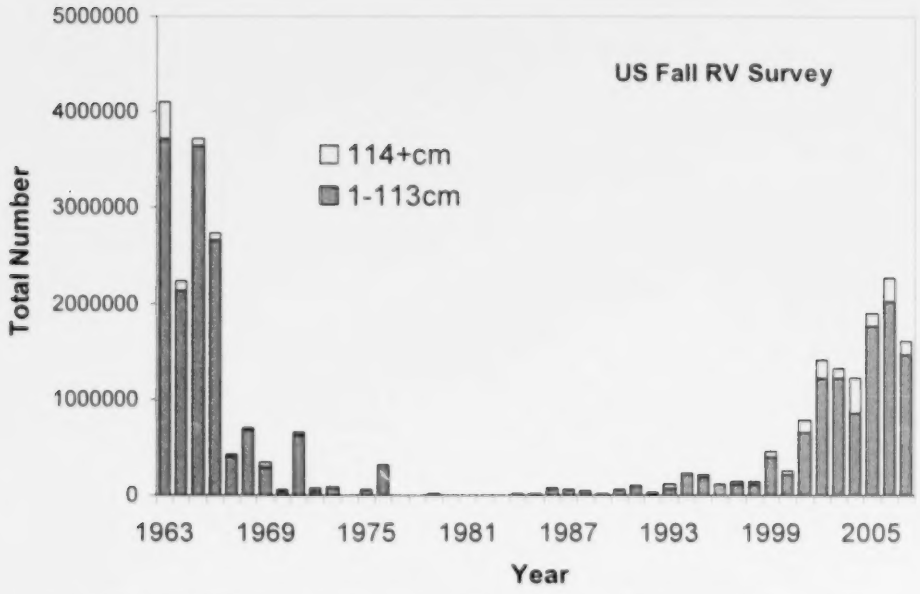


Figure 26. Total abundance of barndoor skate from the USA fall RV survey disaggregated by juveniles (1-113 cm) and adults (≥114 cm).

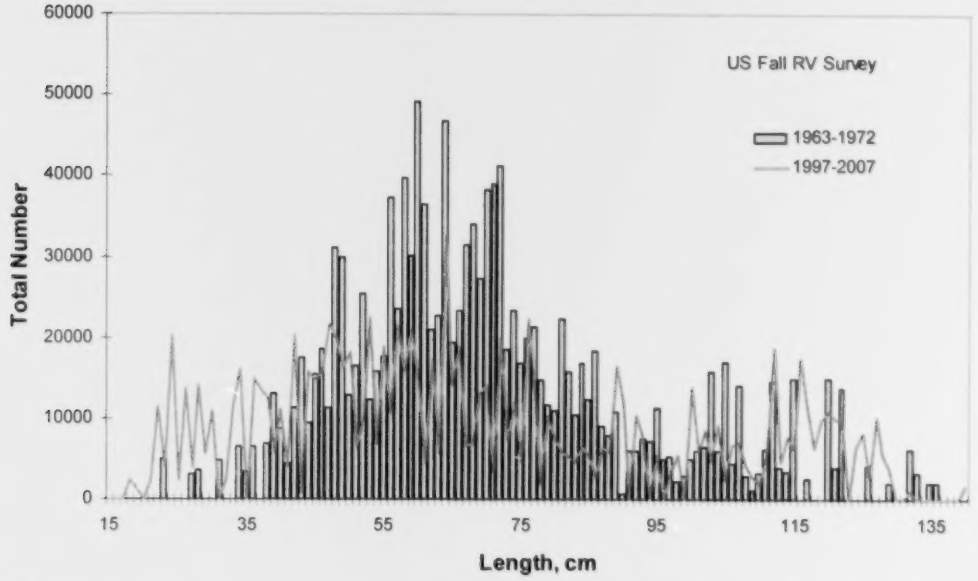


Figure 27. Composite length frequency of barndoor skate from the USA fall RV survey from 1963-1972 and 1997-2007.

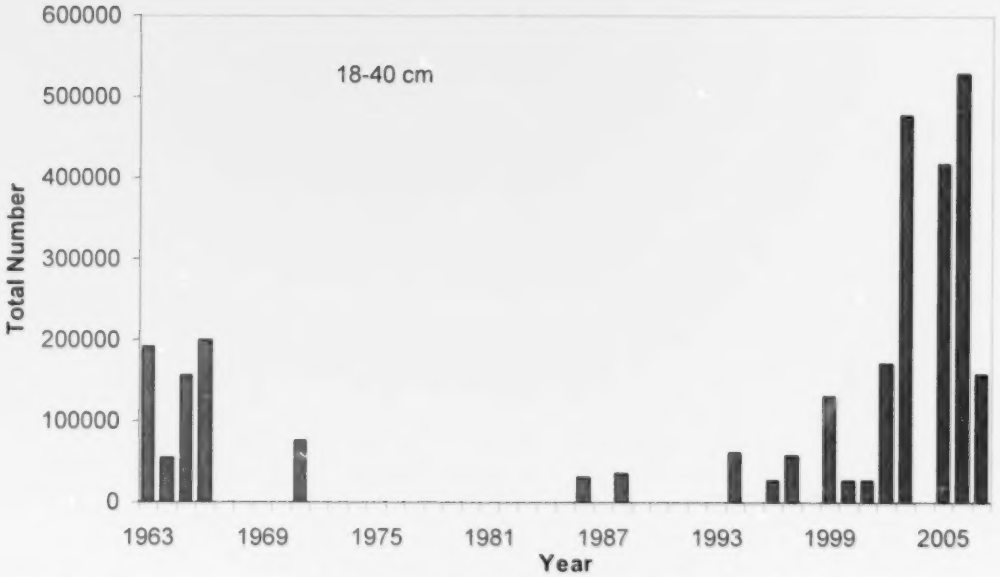


Figure 28. Recruitment of ~ages 0, 1 (18-40 cm) barndoor skate from the USA fall RV survey.

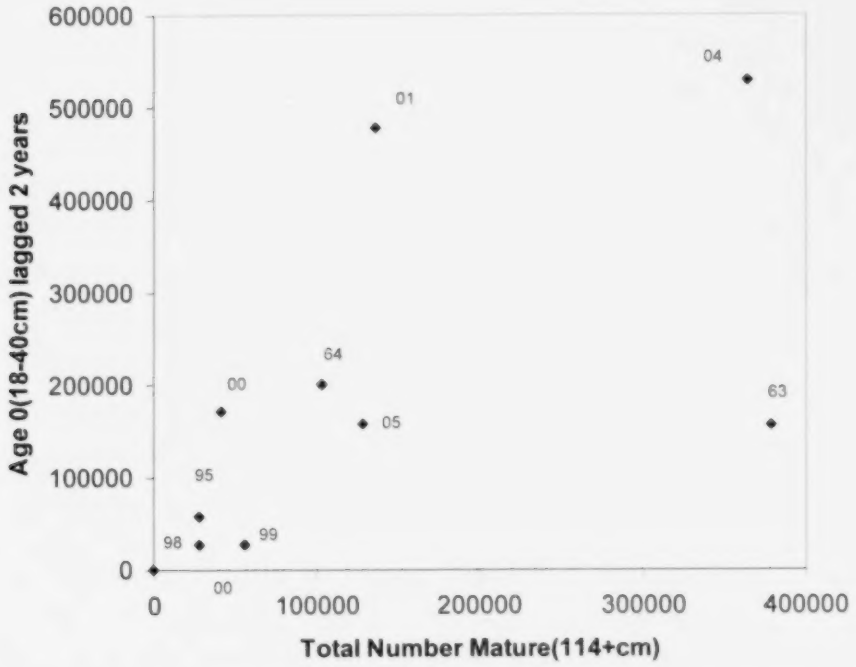


Figure 29. Relationship between number of adults (≥114 cm) and the number of aged 0 fish lagged 2 years. This assumes the incubation time in a purse is 1 year.

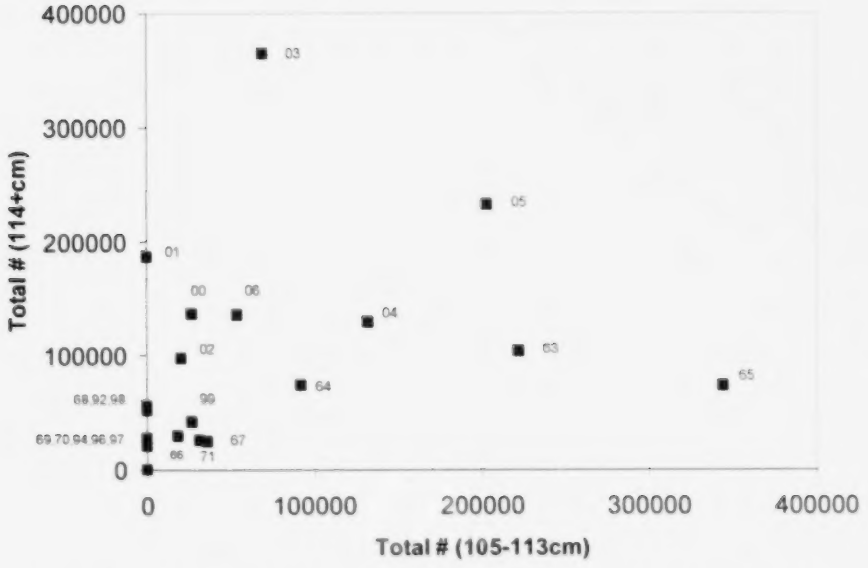


Figure 30. Relationship between the total number of barndoor skate 105-113 cm and the number of adults (≥114 cm) in the following year.

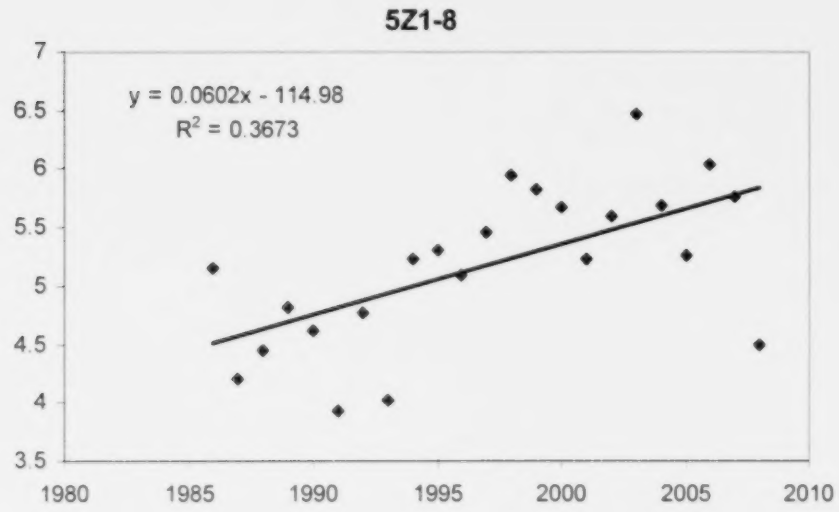


Figure 31. Log transformed (total number) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the Canadian RV survey of Georges Bank, Div. 5Ze, 1986-2008.

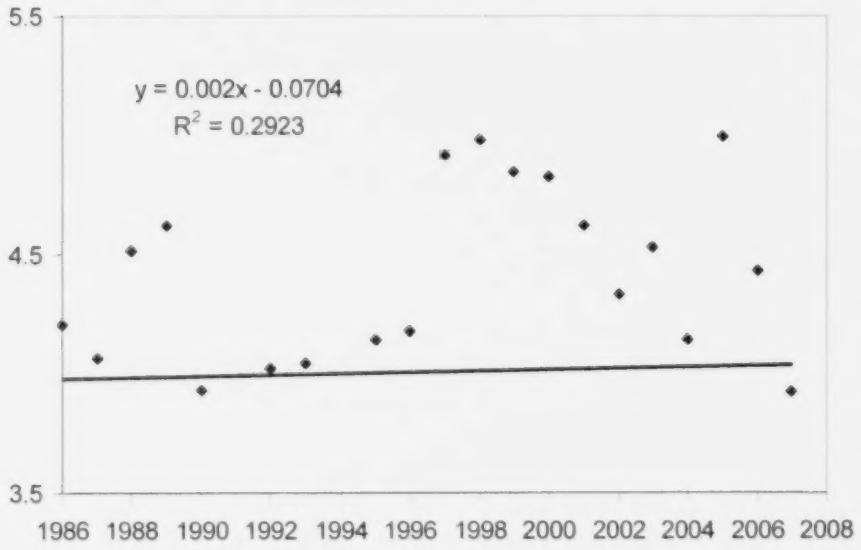


Figure 32. Log transformed (total number) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the Canadian RV survey of Georges Bank, Subdiv. 5Zc, 1986-2008.

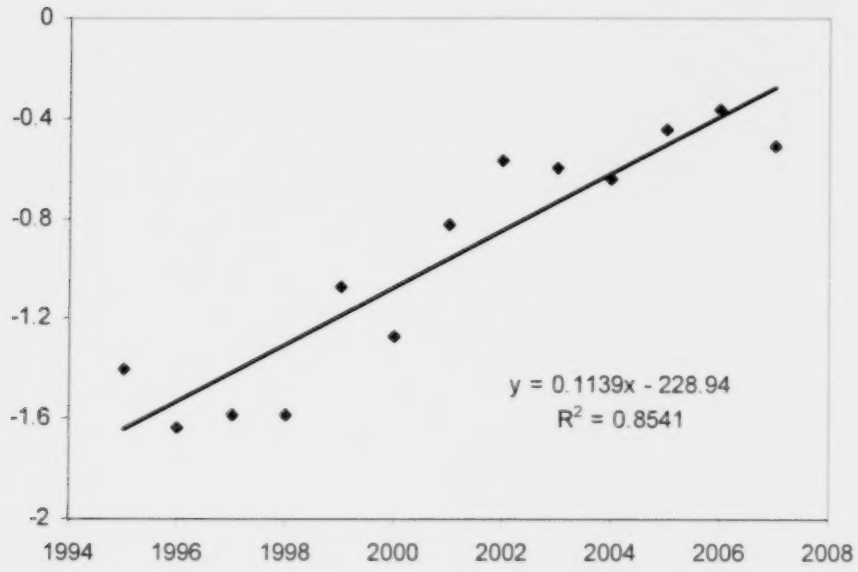


Figure 33. Log transformed (total number) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the entire USA fall RV survey, 1995-2007.

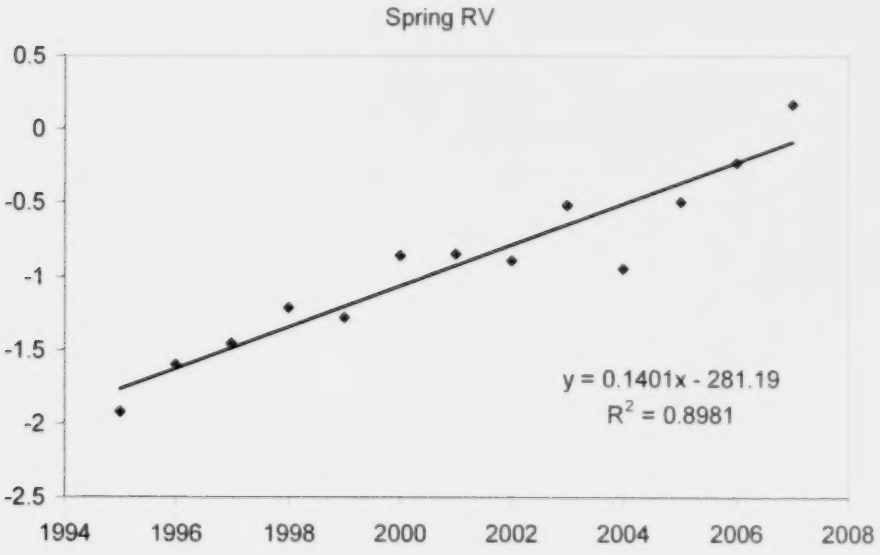


Figure 34. Log transformed (total number) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the entire USA spring RV survey, 1995-2007.

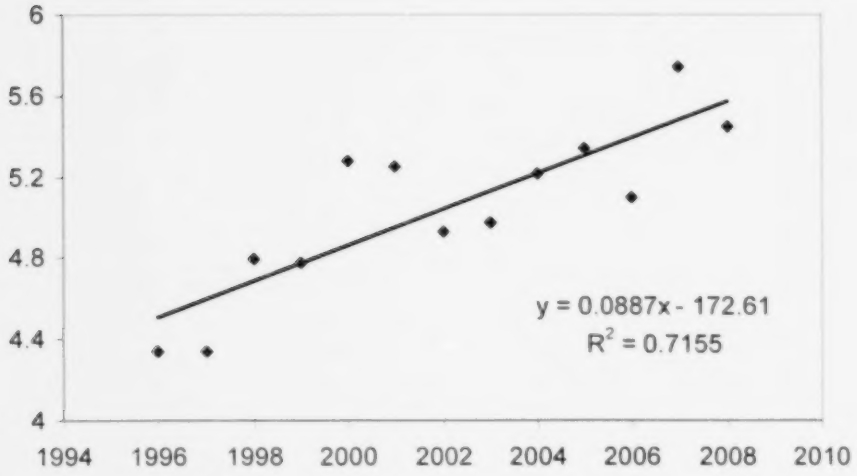


Figure 35. Log transformed (total number) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the Canadian summer RV survey in Div. 4VWX, 1996-2008.

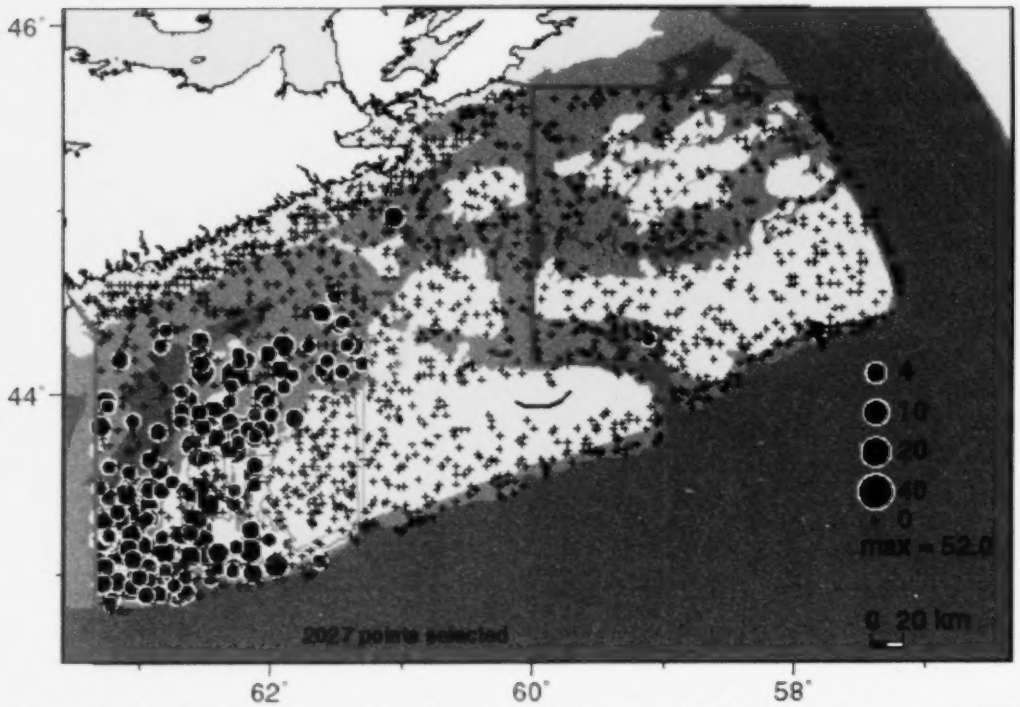


Figure 36. Distribution of barndoor skate as indicated by the 4VsW sentinel survey, 1996-2007. The juvenile haddock closed area in place since 1987 is outlined in red. The 4 core strata (462-465) that have been surveyed annually since 1996 are indicated in green.

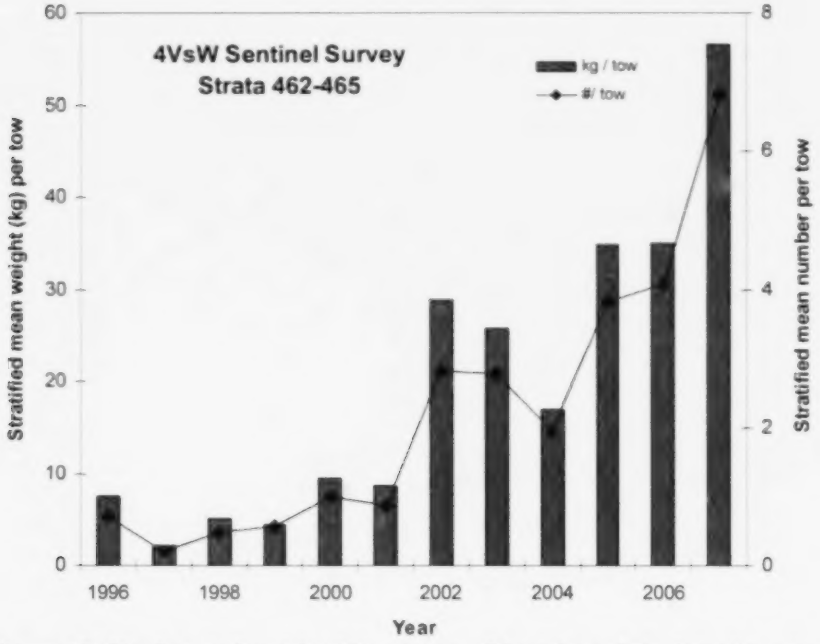


Figure 37. Number and weight (kg) per tow of barndoor skate from the core strata (462-465) of the 4VsW sentinel survey, 1996-2007.

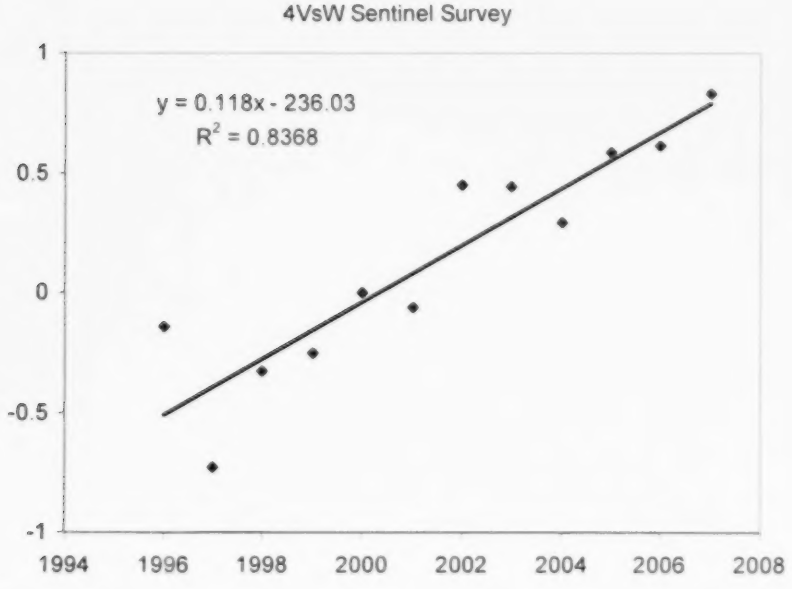


Figure 38. Log transformed (number per tow) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the longline Div. 4VsW sentinel survey.

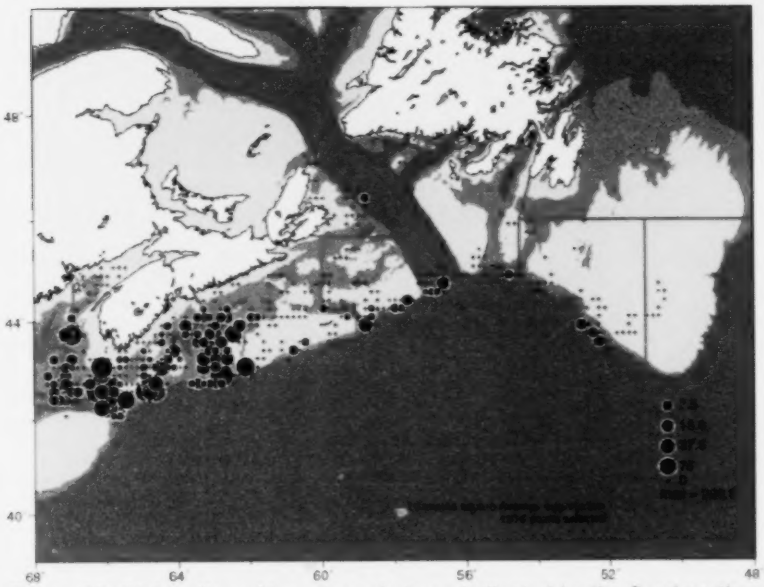


Figure 39. Distribution of barndoor skate as indicated by the fixed portion of the Halibut Industry Survey in Div. 3NOP4VWX5Z, 1997-2007.

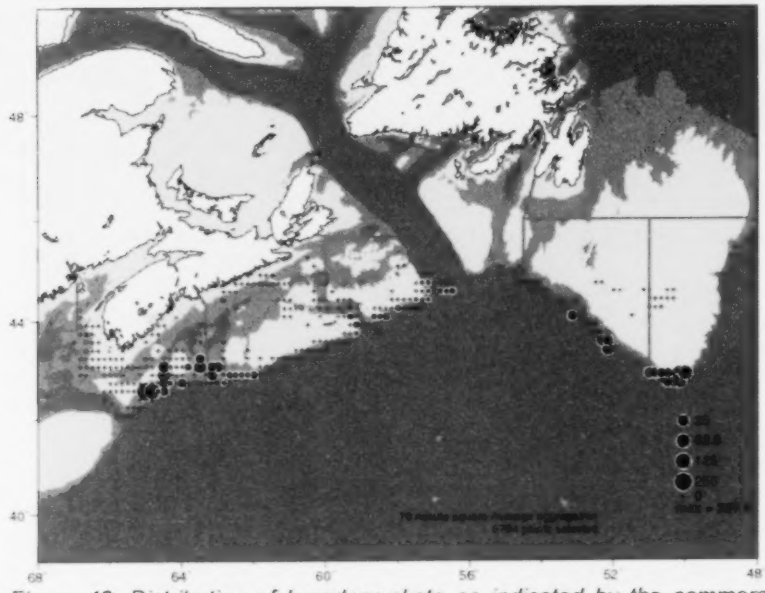


Figure 40. Distribution of barndoor skate as indicated by the commercial index portion of the halibut survey in Div. 3NOP4VWX5Z, 1997-2007.

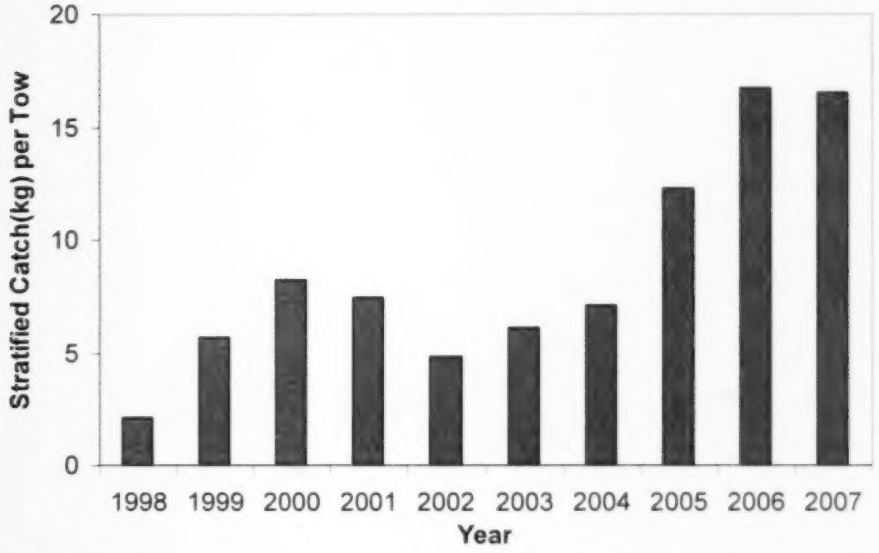


Figure 41. Stratified mean catch (kg) per tow of barndoor skate caught during the Halibut Industry Survey in Div. 3NOP4VWX.

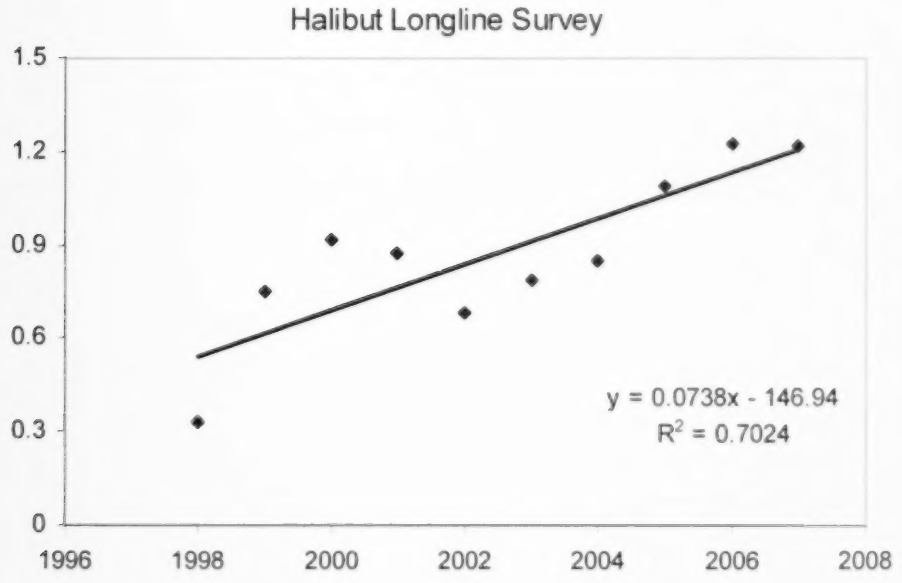


Figure 42. Log transformed (kg per tow) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the fixed station sets of the Halibut Industry Survey in Div. 3NOP4VWX.

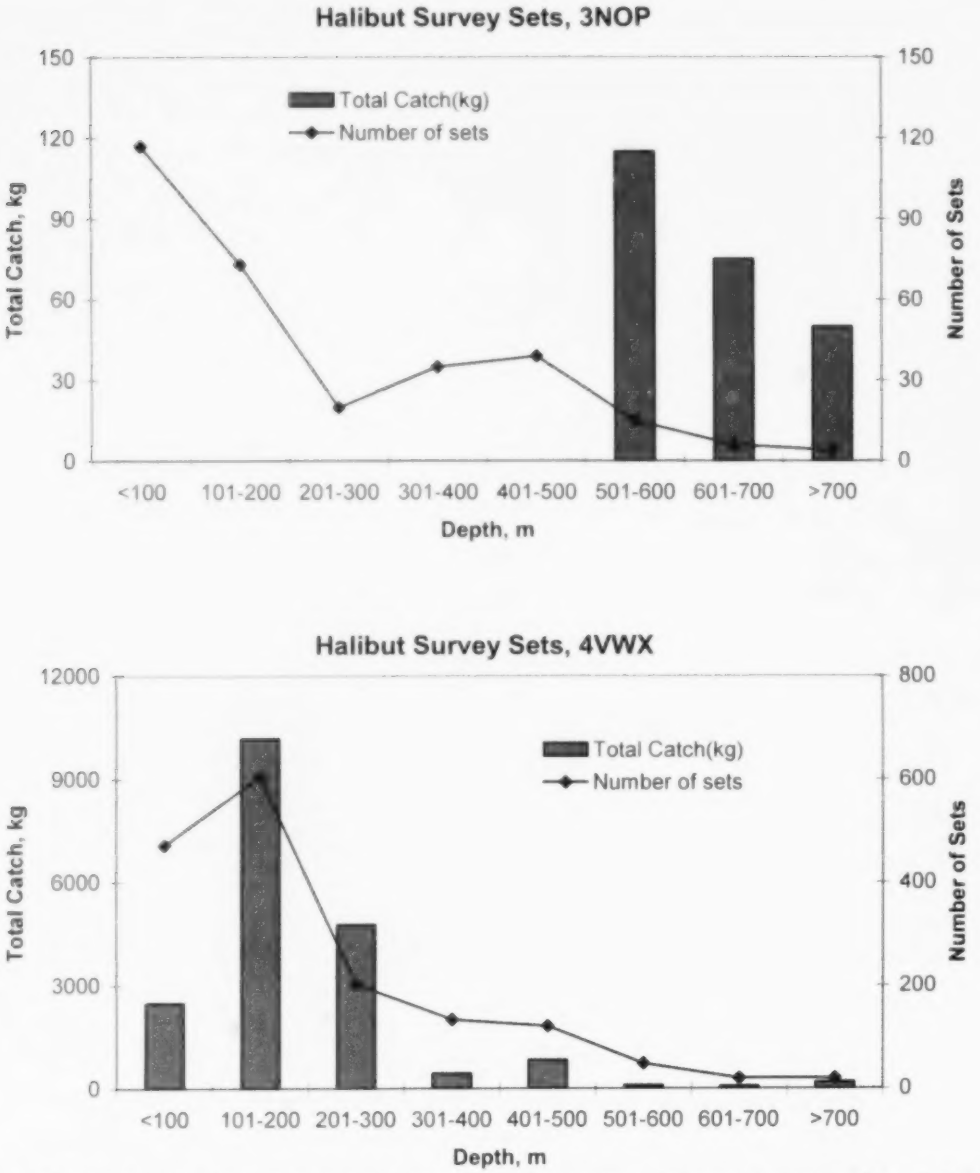
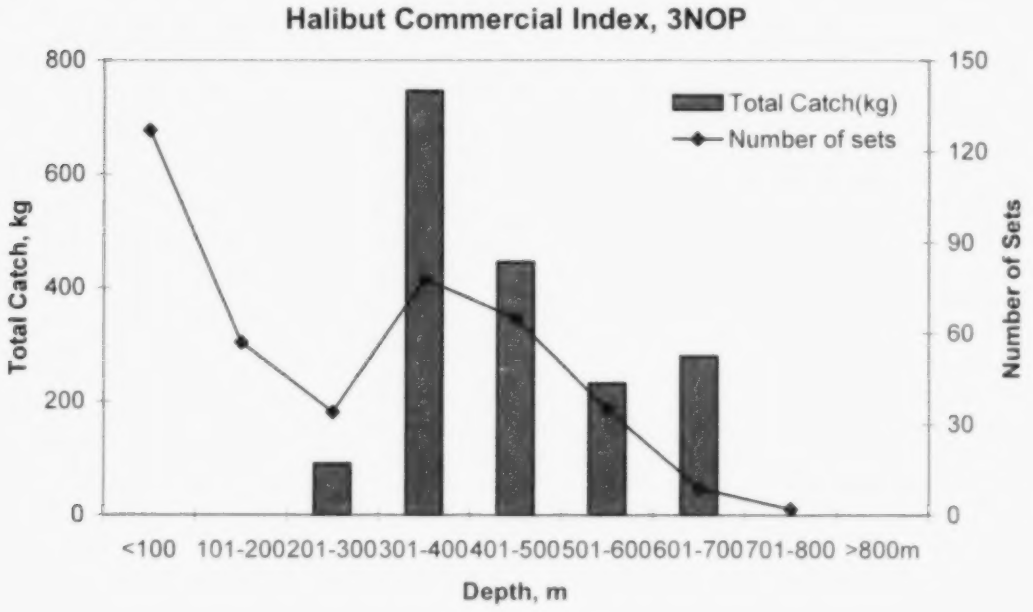


Figure 43. Total catch (kg) of barndoor skate from the Halibut Industry Survey in Div. 4VWX and Div. 3NOP by depth strata in relation to the number of sets within each area, 1997-2007. Maximum depth fished was 929 m.



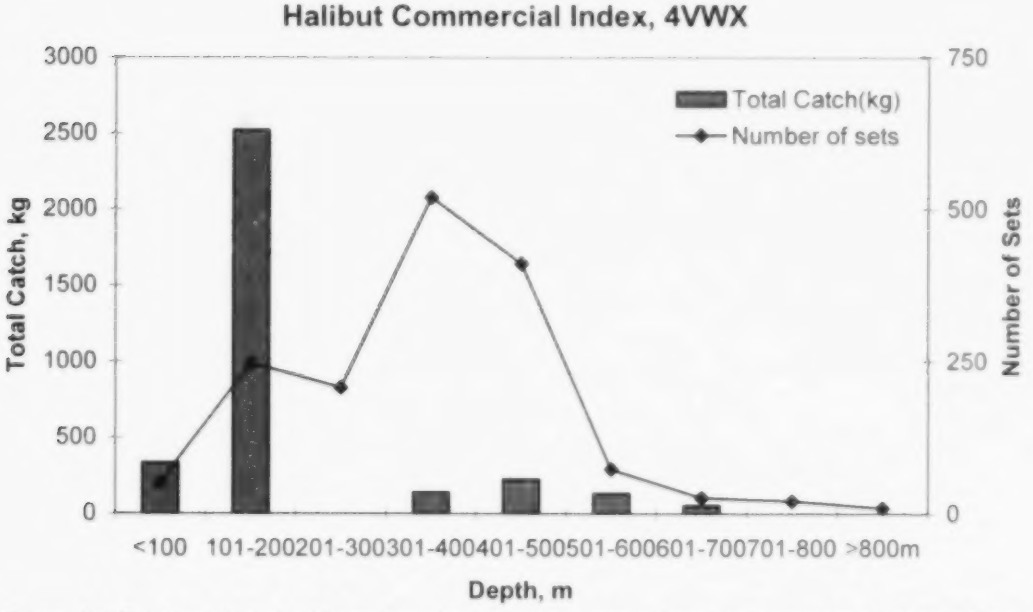


Figure 44. Total catch (kg) of barndoor skate by depth strata from the commercial index phase of the Halibut Industry Survey in Div. 3NOP and Div. 4VWX, 1997-2007.

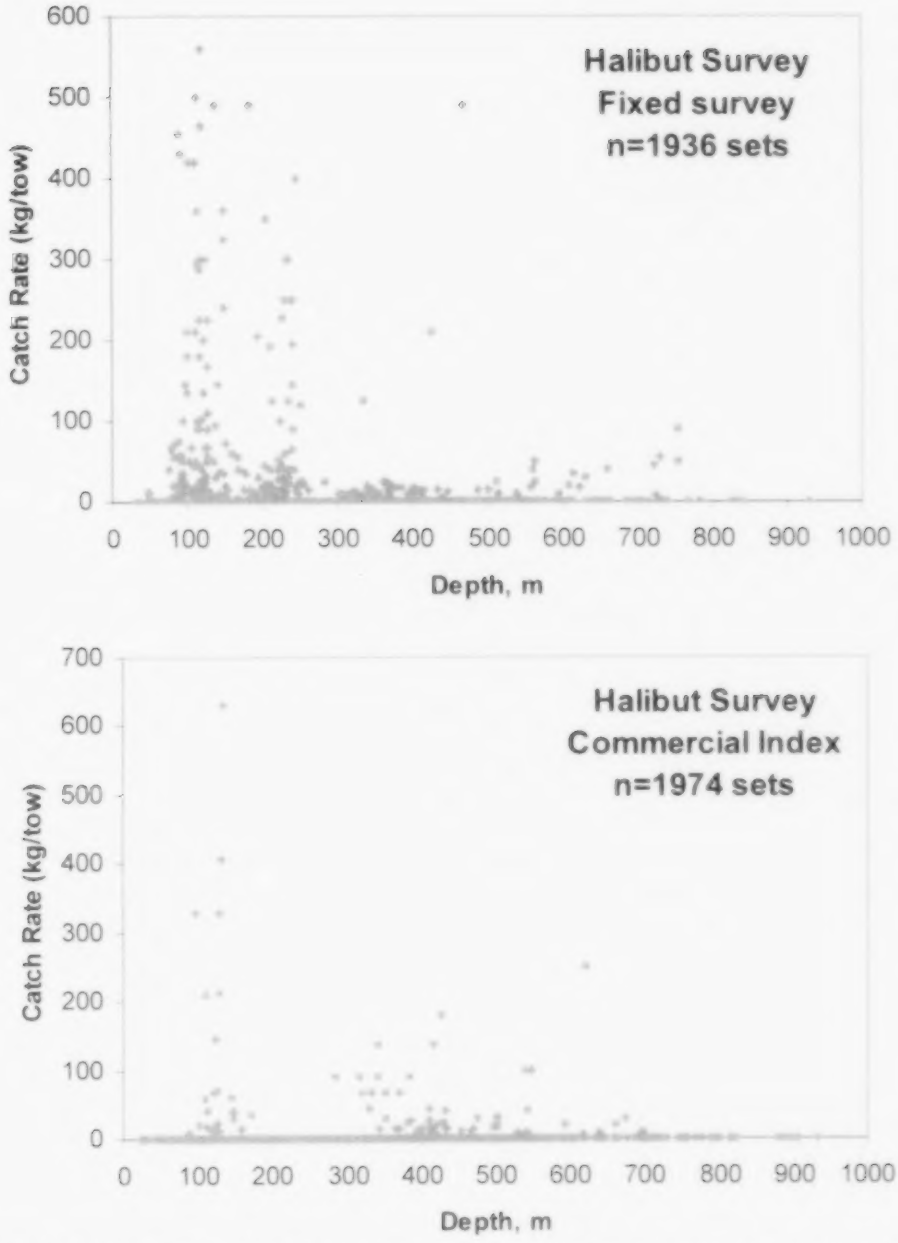


Figure 45. Catch rate (kg/tow) of barndoor skate by depth, m as indicated by the Halibut Industry Survey in Div. 3NOP4VWX5Z.

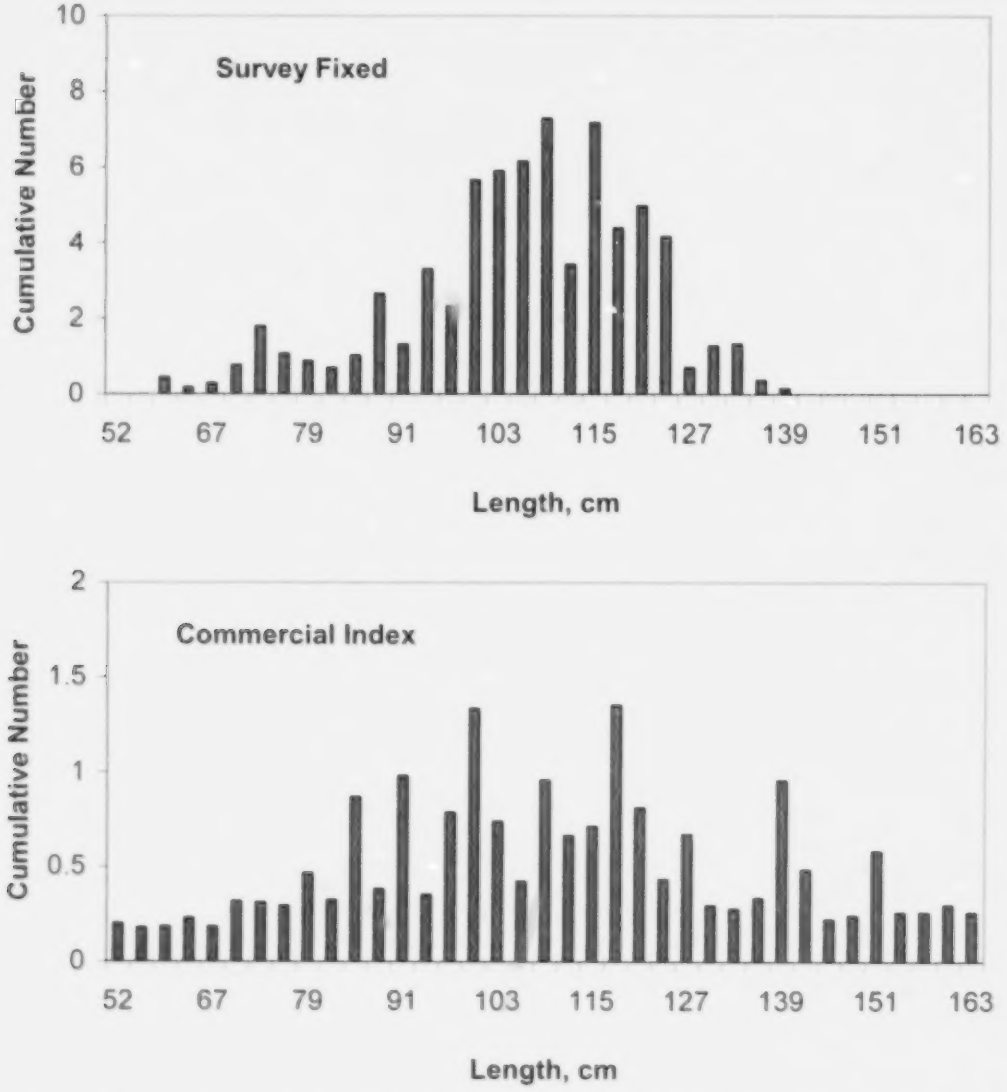


Figure 46. Cumulative length frequency of barndoor skate caught during the fixed survey (1998-2005, 2007) and the commercial index sets (1998, 2007) of the Halibut Industry Survey in Div. 3NOP4VWX.

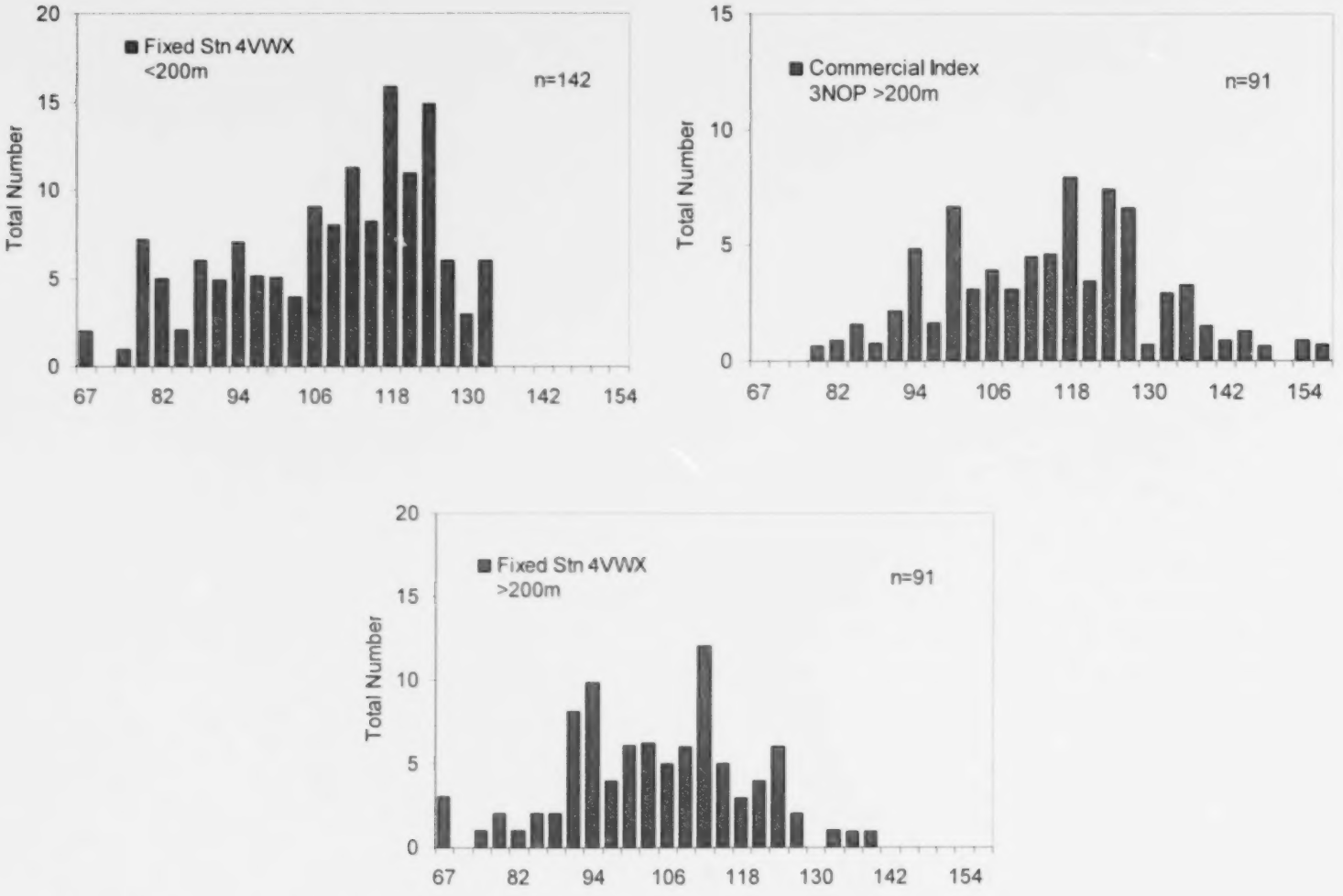


Figure 47. Preliminary cumulative length frequencies of barndoor skate from the 2008 Halibut Industry Survey.

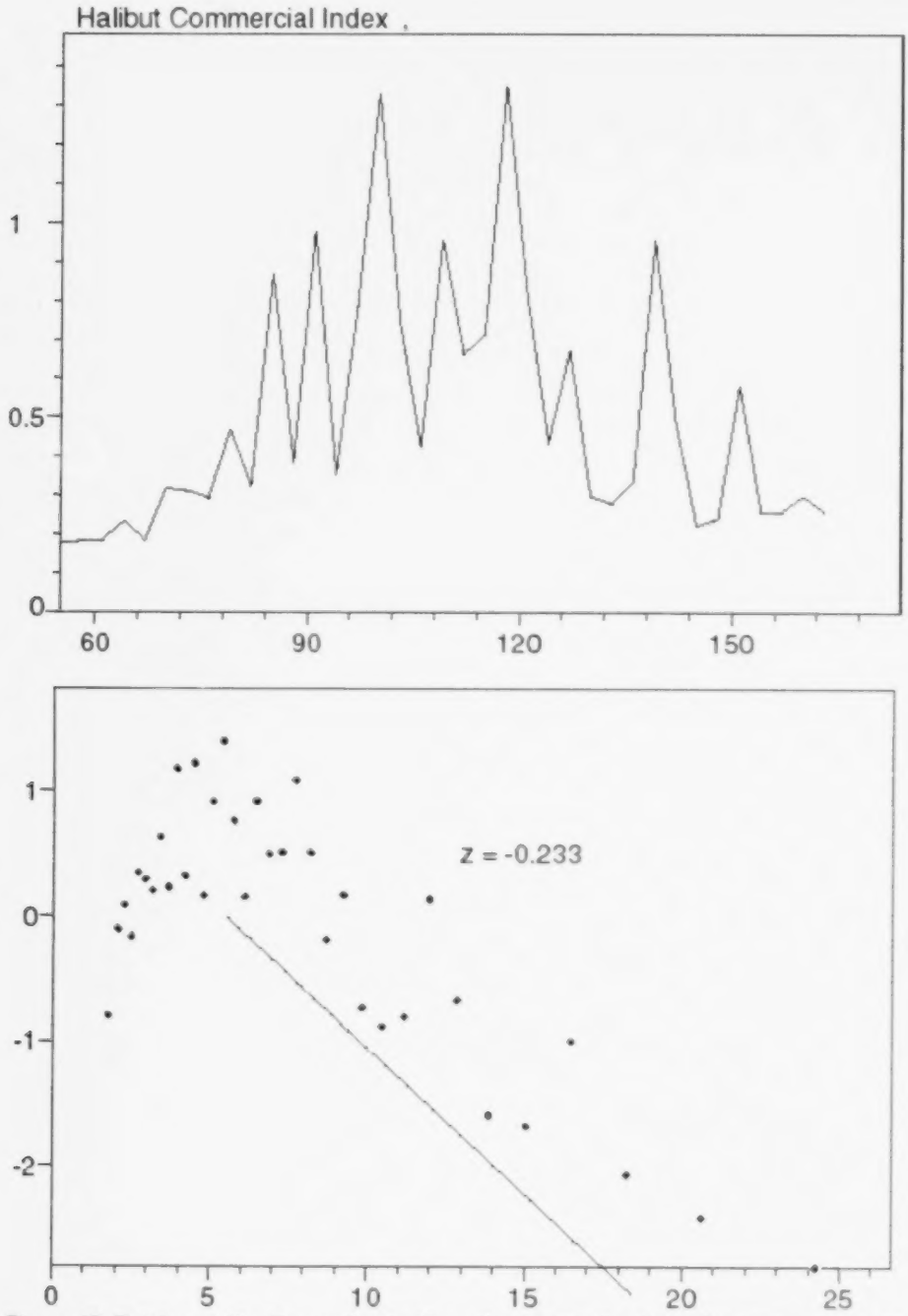


Figure 48. Total mortality, Z as estimated from the descending limb of the commercial index portion of the Halibut Industry Survey in 1998.

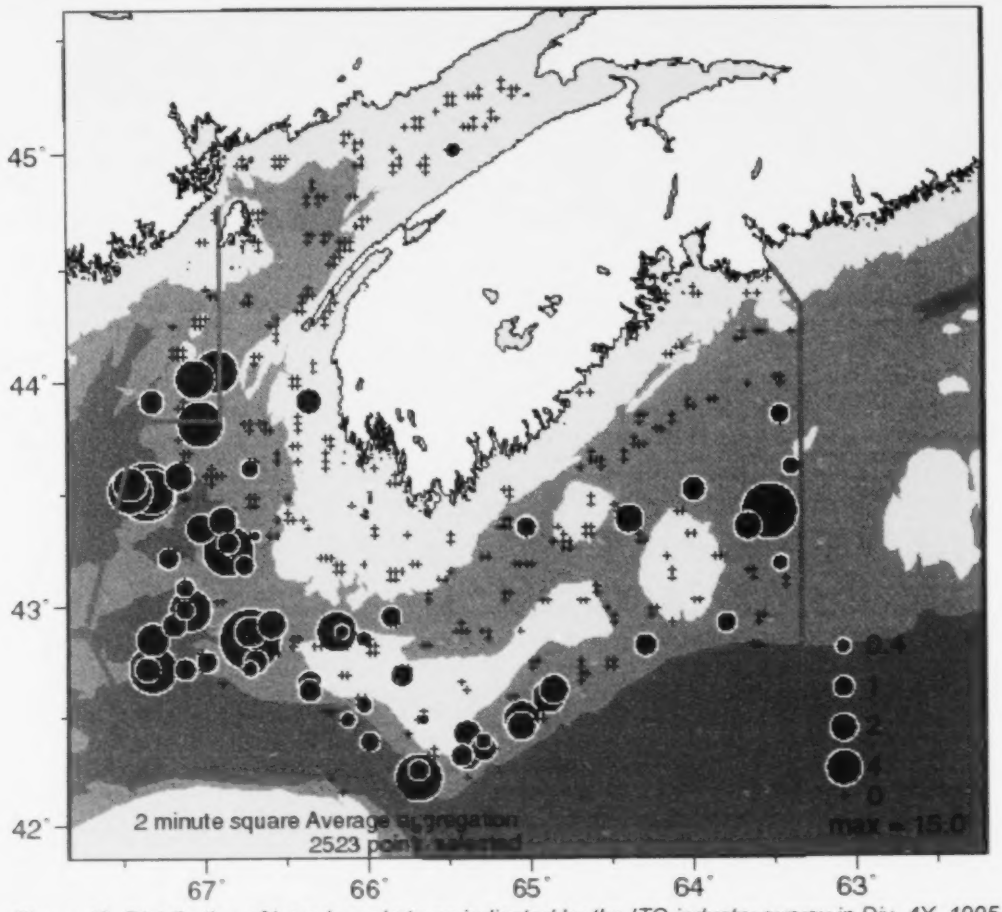


Figure 49. Distribution of barndoor skate as indicated by the ITQ industry survey in Div. 4X, 1995-2008.

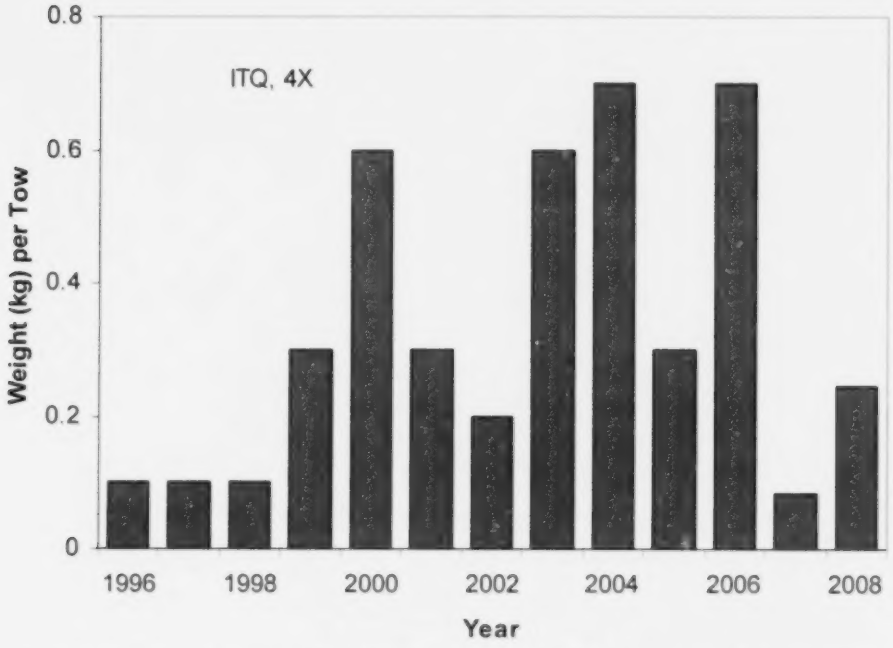


Figure 50. Abundance (kg per tow) of barndoor skate from the Div. 4X ITQ industry survey.

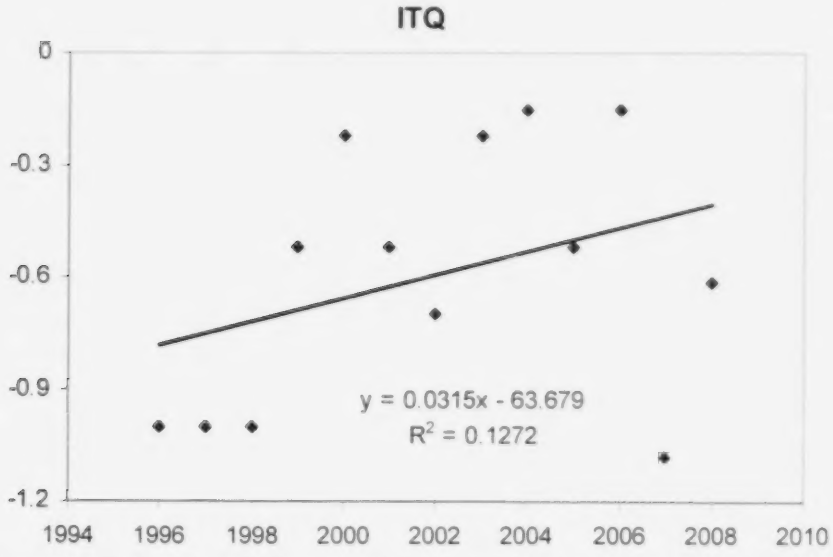


Figure 51. Log transformed (kg per tow) and corresponding linear regression of the catch rate of all sizes of barndoor skate from the otter trawl ITQ industry survey in Div. 4X.

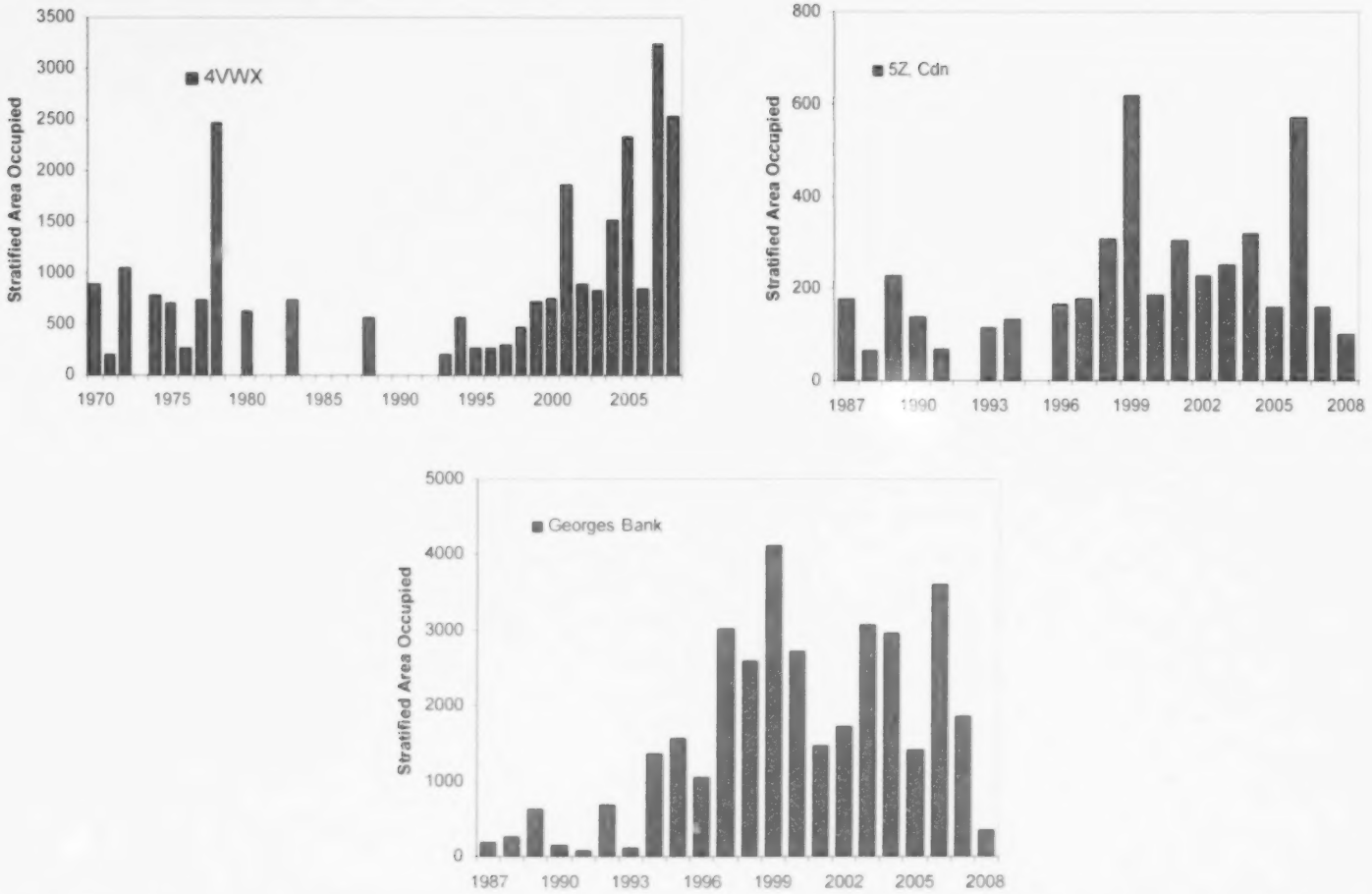


Figure 52. Area of occupancy (nm^2) for the Scotian Shelf (Div. 4VWX), the Canadian side of Georges Bank (Subdiv. 5Zc), and Georges Bank (Div. 5Ze).

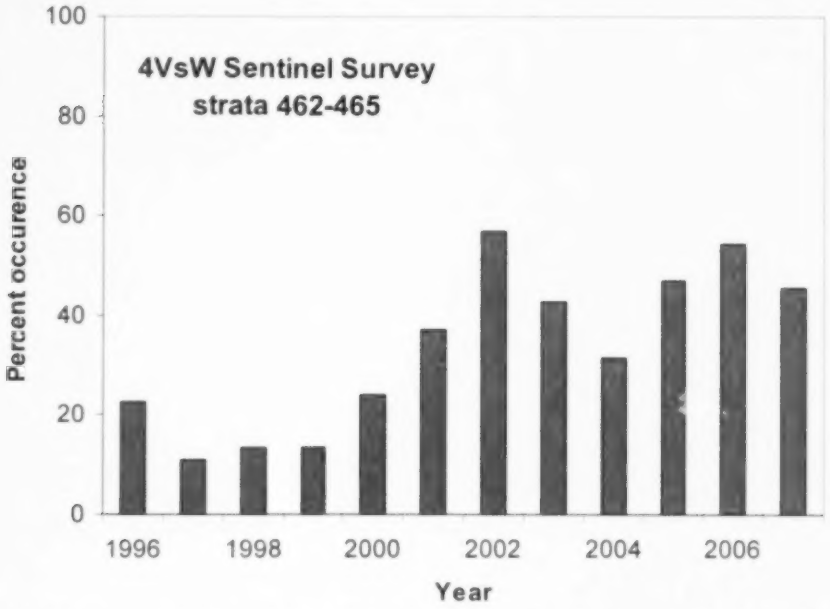


Figure 53. Percentage of sets in which barndoor skate were caught in the core strata (462-465) of the 4VsW sentinel survey. Total number of sets in this core area averaged 45 from 1996-2000 and 35 since 2001.

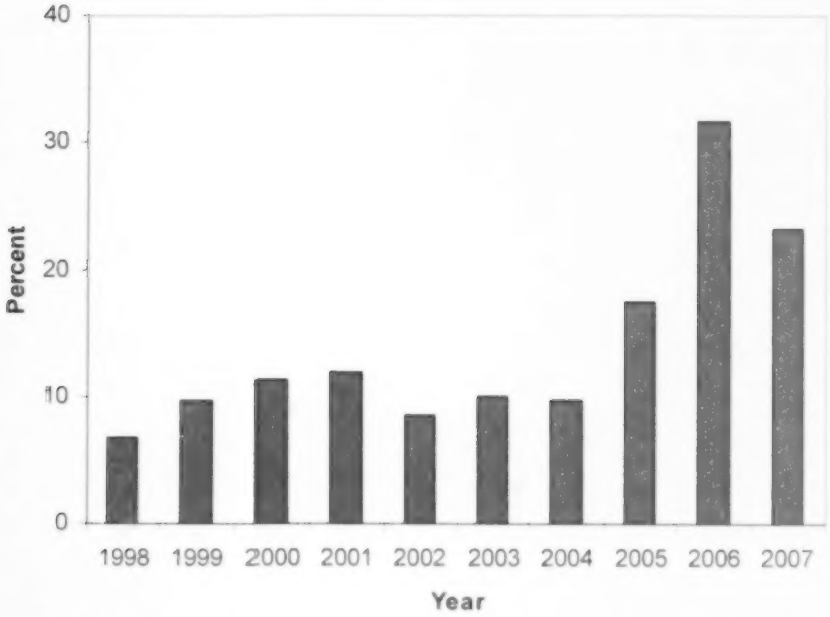


Figure 54. Percent of sets in which barndoor skate were caught during the fixed survey sets of the Halibut Industry Survey.

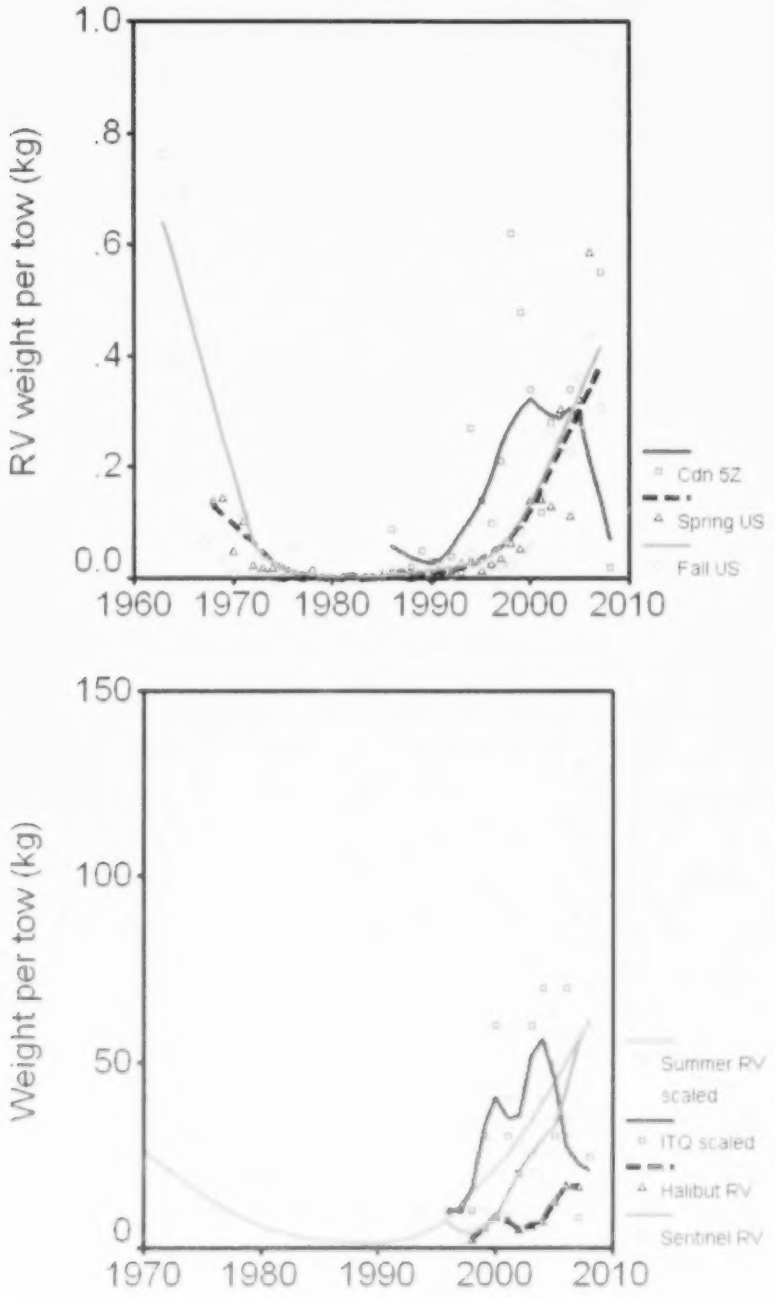


Figure 55. LOESS curves for all survey indices in Div. 5Z (upper panel) and Div. 4VWX (lower panel).

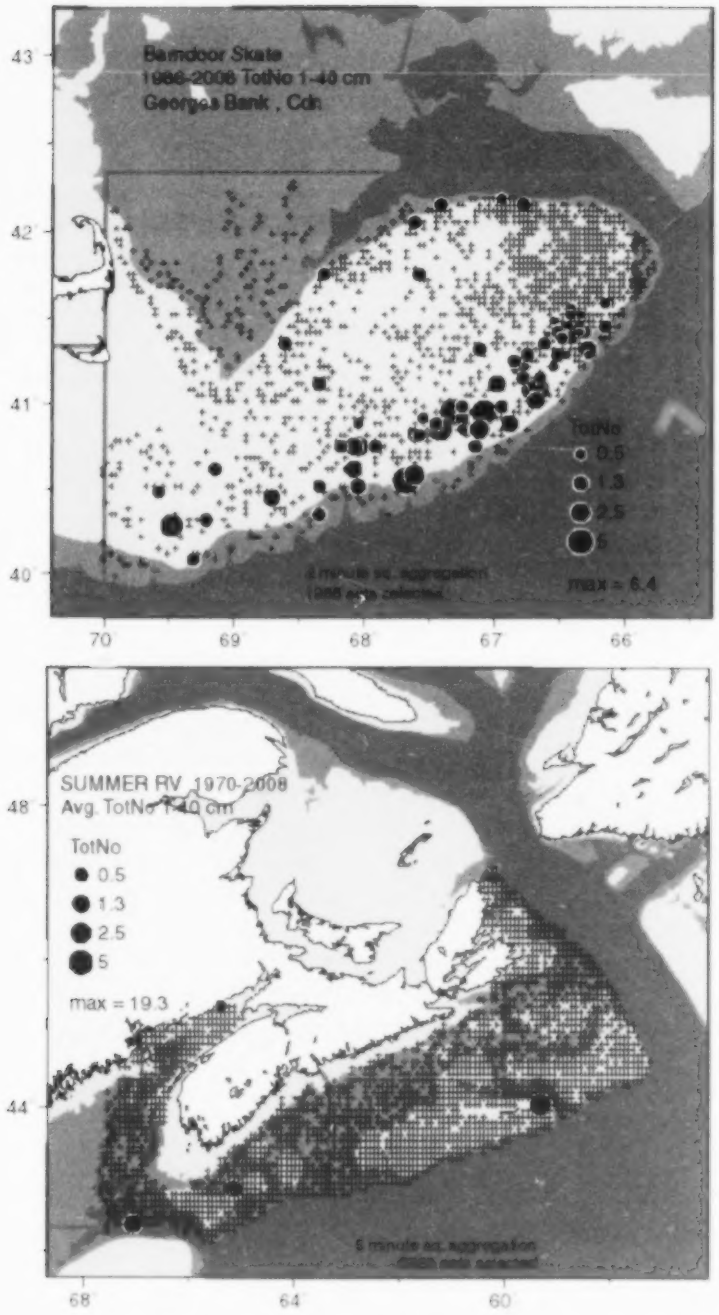
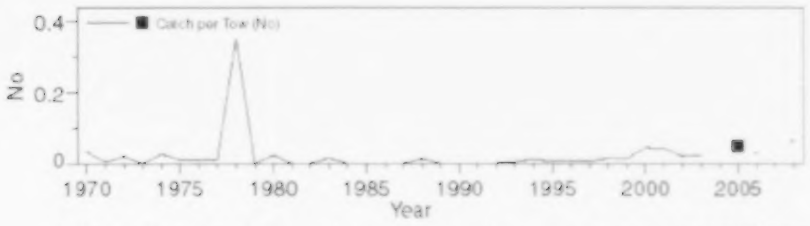
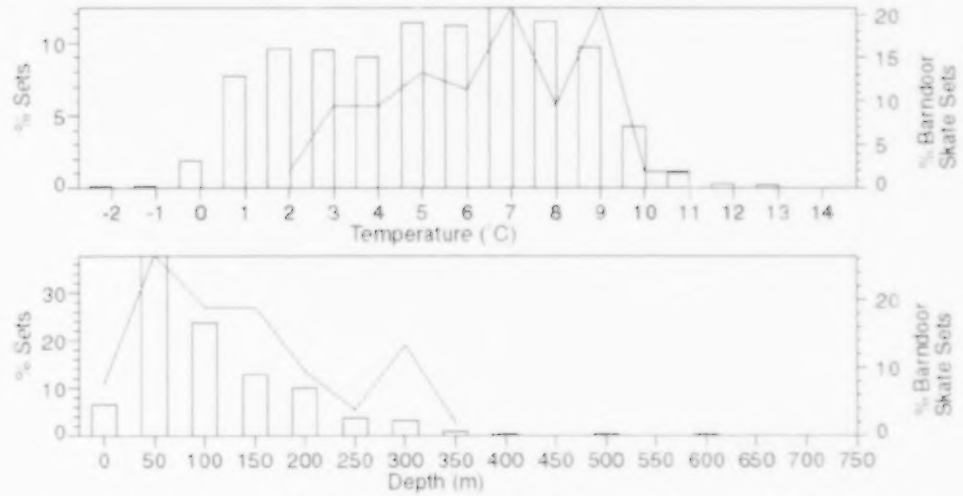


Figure 56. Distribution of barndoor skate as indicated by the Canadian winter (top panel) and summer RV (bottom panel) surveys for length group 1-40 cm.

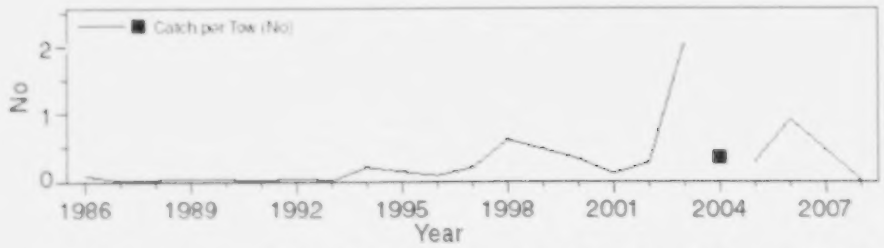


Barndoor Skate stratified mean number caught per tow from the SUMMER Ecosystem surveys. The catch for 2004 was sampled using the MV Teleost. It has not been calibrated, and should not be compared to the earlier time series.

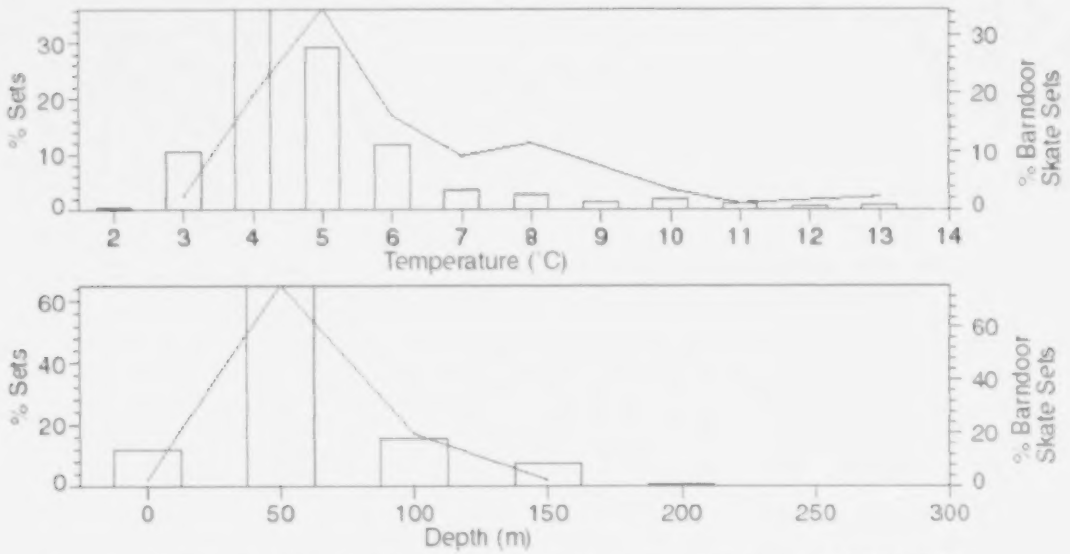


Temperature and depth distribution of Barndoor Skate captured from the SUMMER Ecosystem surveys 1970-2008. Shown for each variable is percentage of sets with Barndoor Skate within given temperature or depth intervals (line) and percentage of all sets within different temperature or depth intervals (bar graph).

Figure 57. Temperature and depth preferences of barndoor skate as indicated by the summer RV survey in Div. 4VWX.



Barndoor Skate stratified mean number caught per tow from the GEORGES Ecosystem surveys. The catch for 2004 was sampled using the MV Teleost. It has not been calibrated, and should not be compared to the earlier time series.



Temperature and depth distribution of Barndoor Skate captured from the GEORGES Ecosystem surveys 1986-2008. Shown for each variable is percentage of sets with Barndoor Skate within given temperature or depth intervals (line) and percentage of all sets within different temperature or depth intervals (bar graph).

Figure 58. Temperature depth preferences of barndoor skate as indicated by the Georges Bank RV survey in Div. 5Ze.

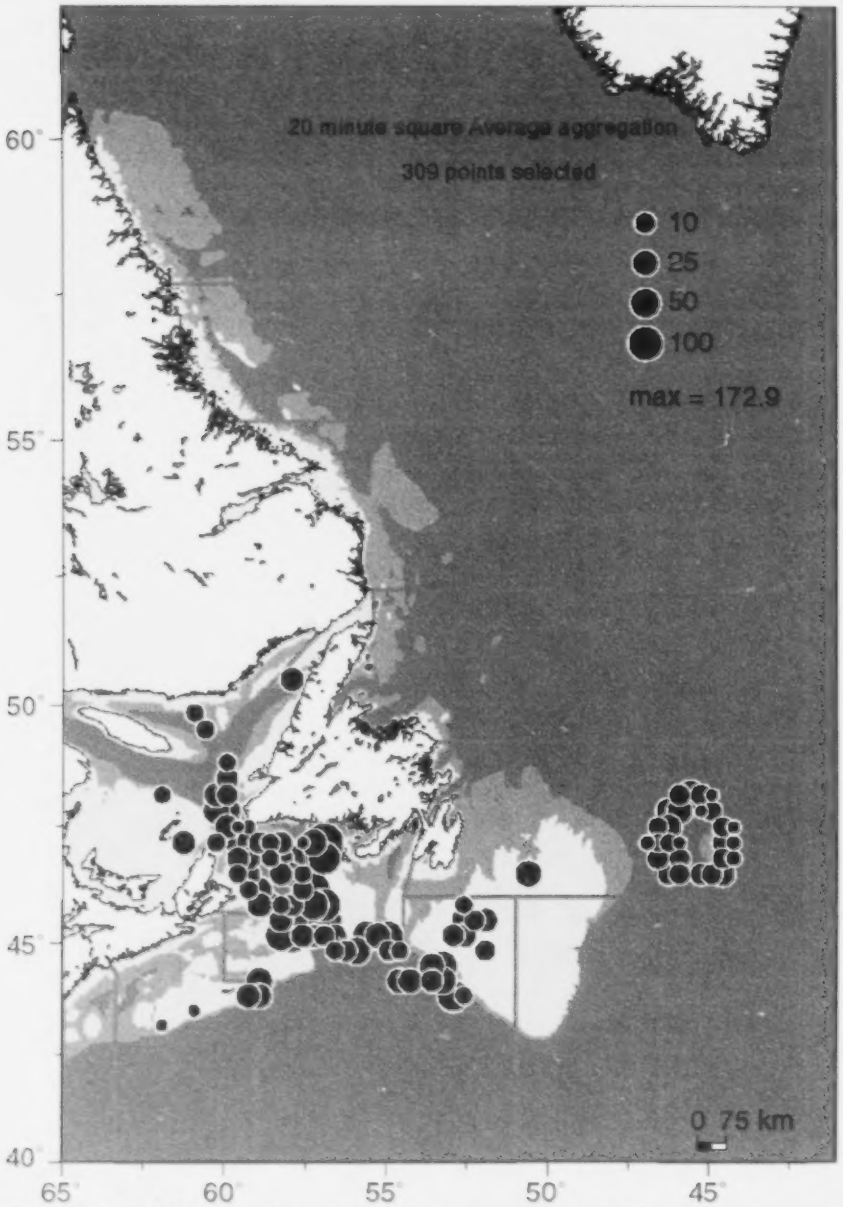


Figure 59. Distribution of barndoor skate from commercial fisheries as determined by the Newfoundland Observer Program since 1978.

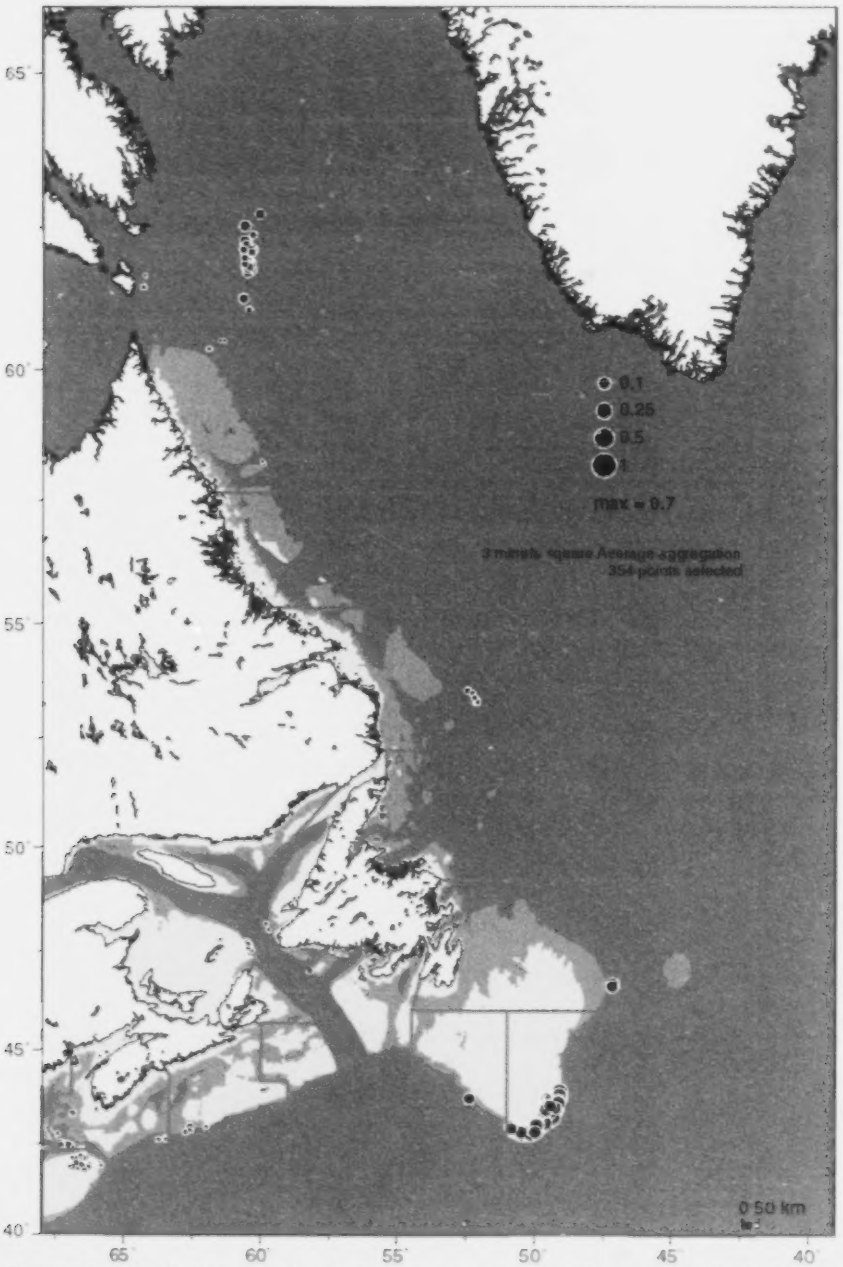


Figure 60. Distribution of white skate from commercial fisheries as indicated by reports from the Maritimes Observer Program since 1978.

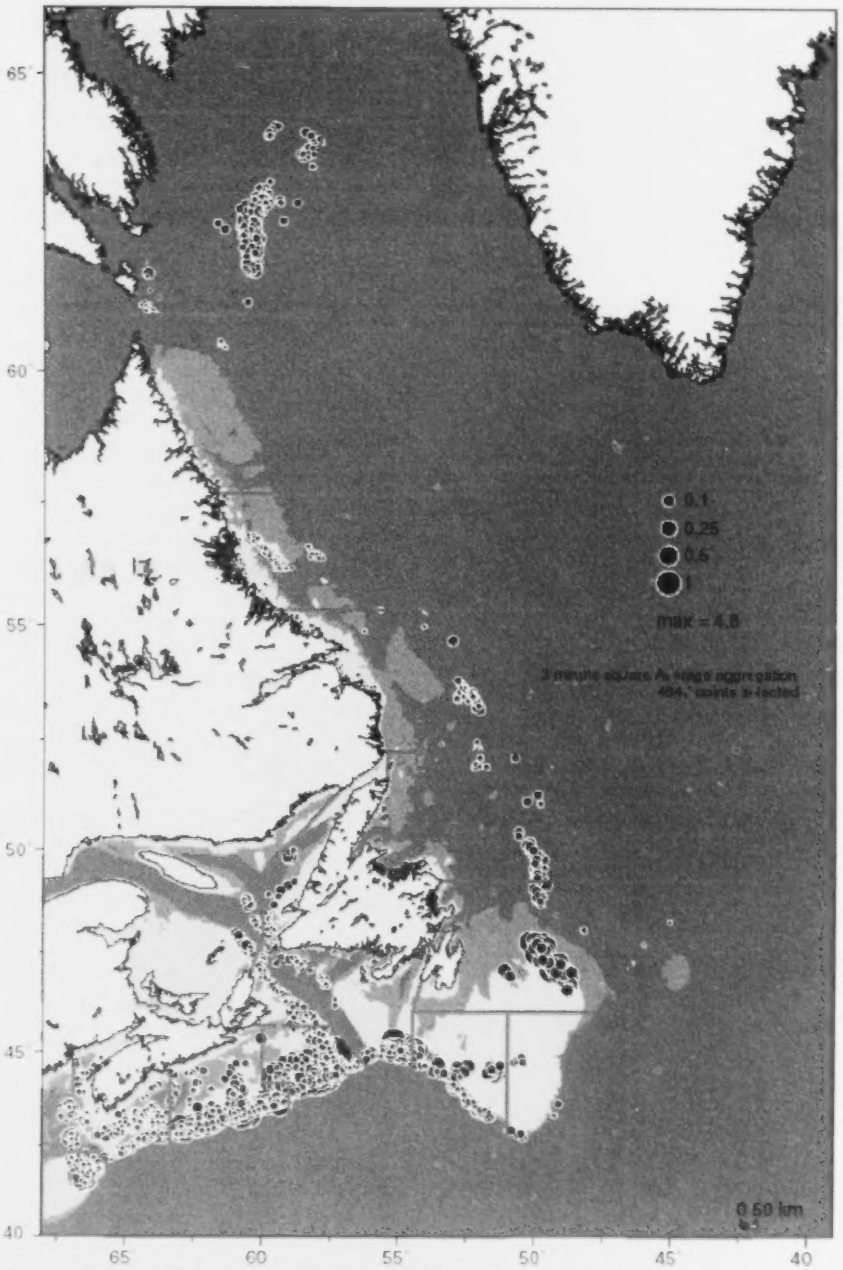


Figure 61. Distribution of spinytail skate in the northwest Atlantic as indicated by reports from the Maritimes Observer Program from 1978-2008.

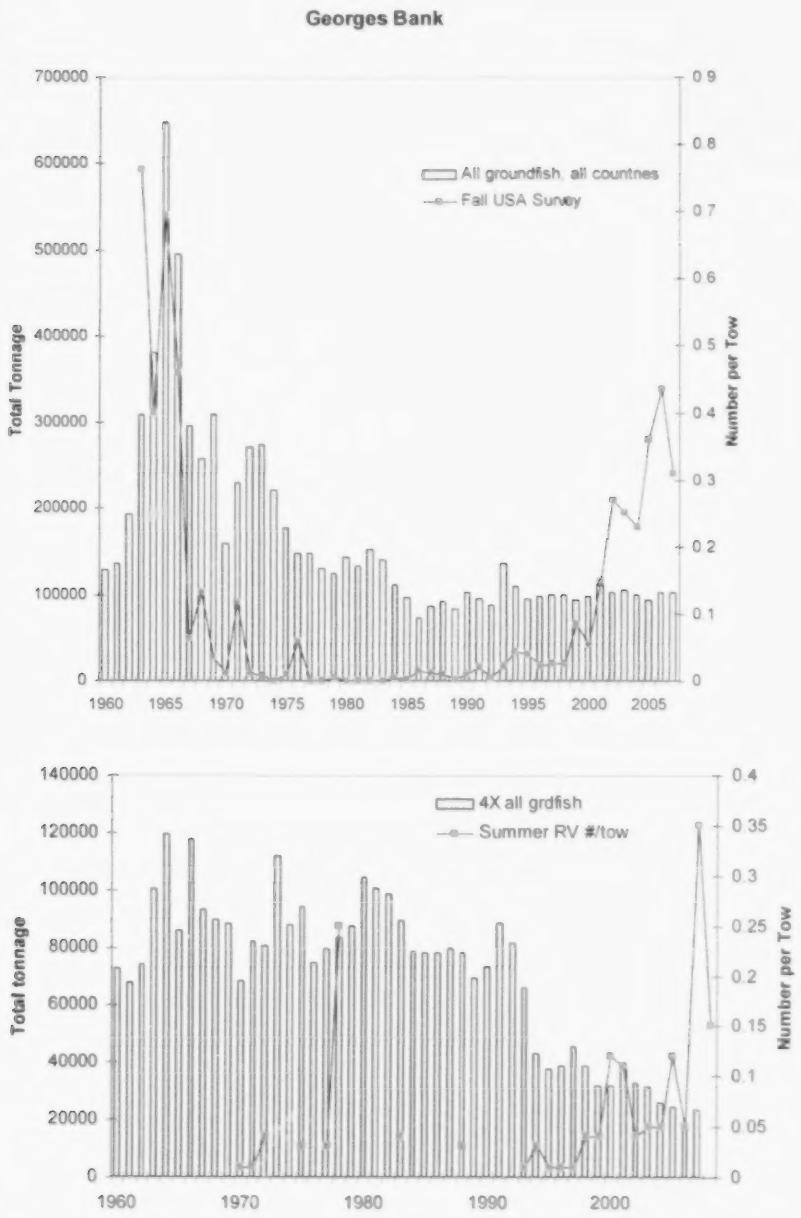


Figure 62. Total reported landings, t of all groundfish from all countries (NAFO statistics) in Div. 5Z (top) and Div. 4X (bottom panel).

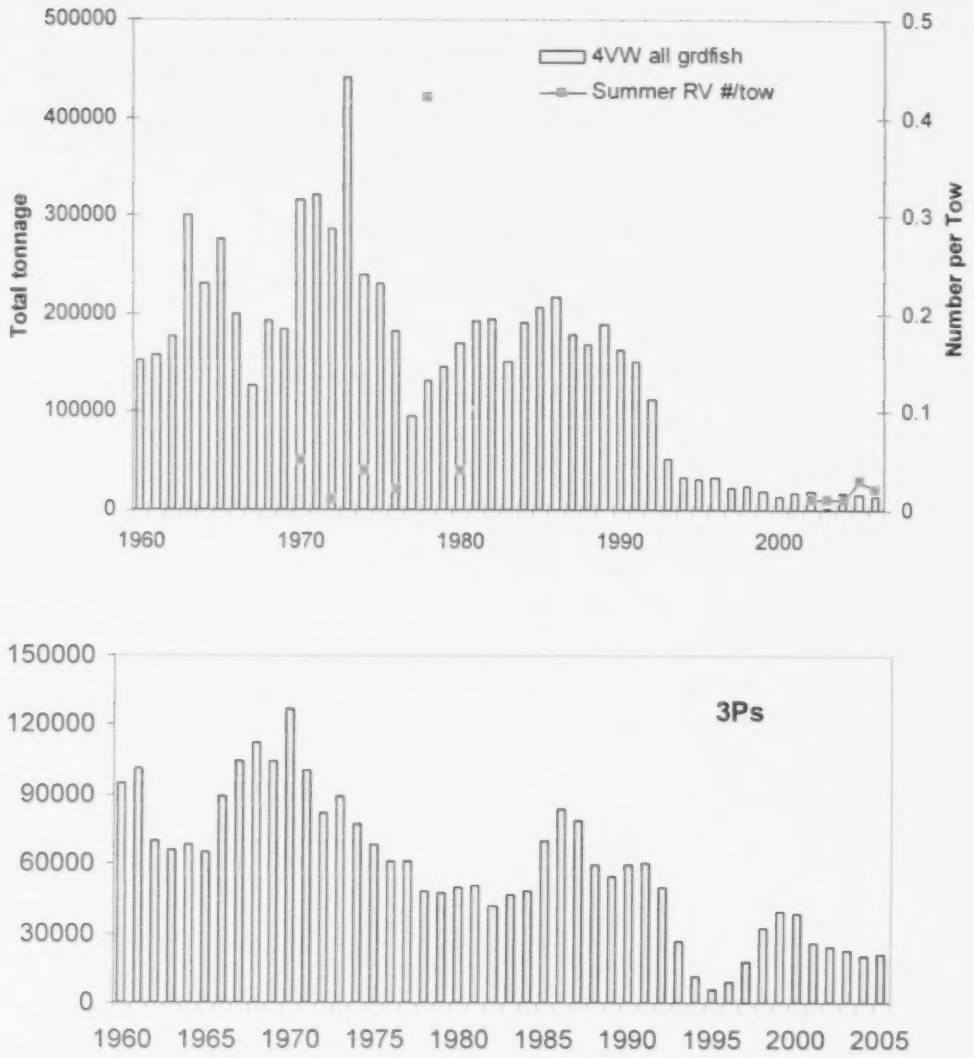


Figure 63. Total reported landings, t of all groundfish from all countries (NAFO statistics) in Div. 4VW (top) and Subdiv. 3Ps (bottom panel).

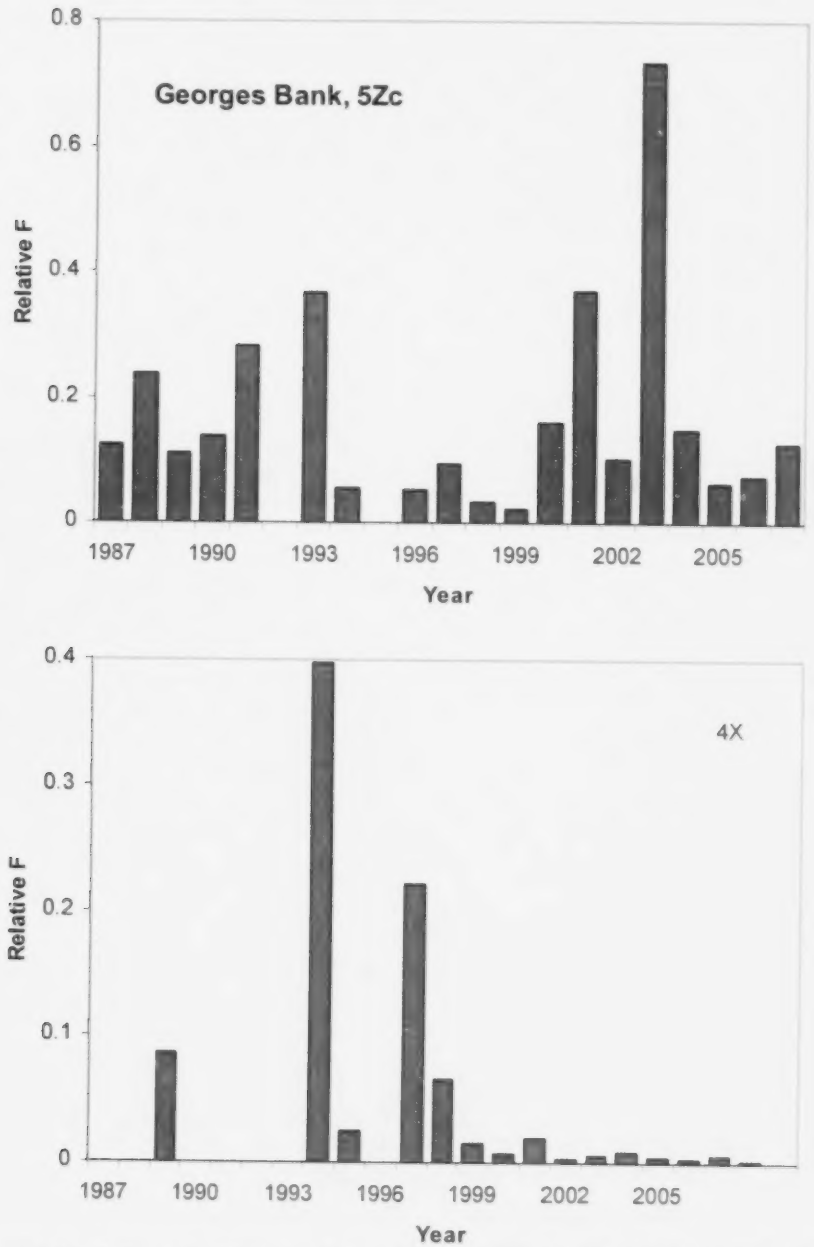


Figure 64. Estimates of Relative F from Georges Bank (Subdiv. 5Zc) and Div 4X based on the biomass estimates (q=0.1) from the Canadian winter and summer RV surveys respectively and estimated bycatch from fisheries in those same areas.

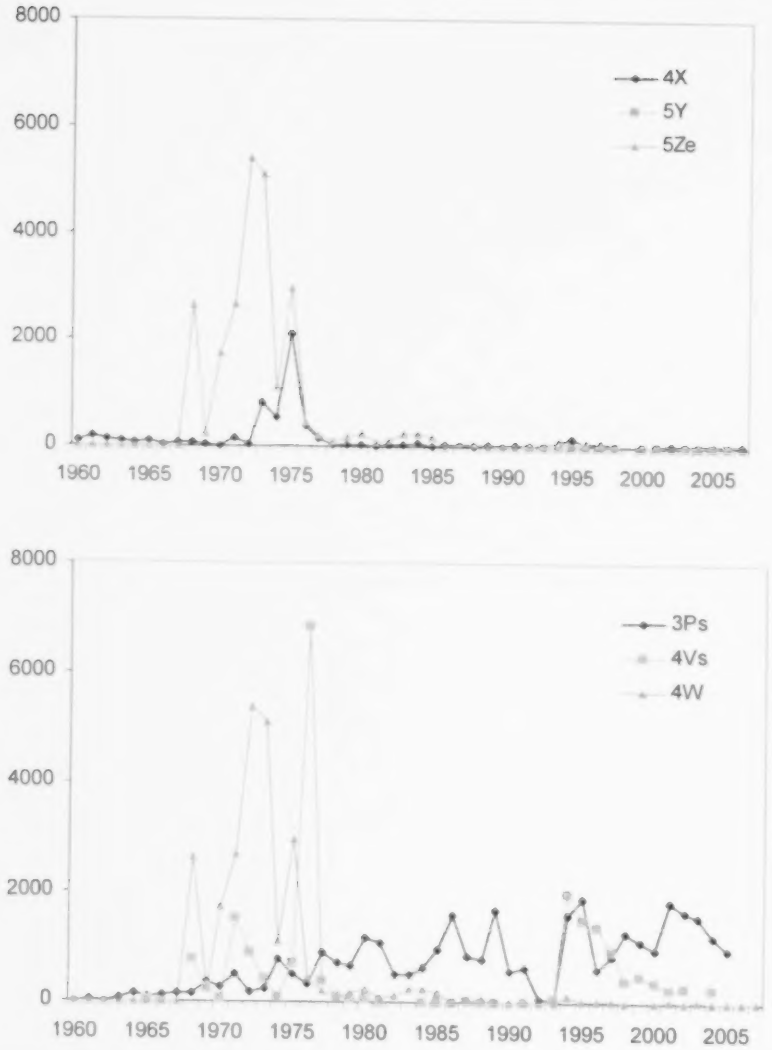


Figure 65. Reported skate landings from Divs. 5Z, 4X, 4VW and Subdiv.3PS.

APPENDICES

Appendix A: Ecosystem Considerations

Methods

Barndoor Skate Food Habits

Two sources of data on barndoor skate food habits were obtained. The first source of diet data were from the DFO food habits database, which has information on 133 barndoor skate stomachs sampled between 1963 and 1966 in Div. 4VWX during spring and summer surveys. Based on Gedamke (2006), the food habits data (weight % and frequency %) were analysed given for both the overall data and separate size classes as ontogenetic shifts in diet have been reported previously (Gedamke, 2006). The size classes and respective sample sizes were 35-70 cm n=14, 70-105 cm n=65 and >105 cm n=54 (Figure A1 lower).

The second data source consisted of 273 barndoor skate, which were sampled from 1999-2003 on Georges Bank (Gedamke, 2006). Food habits summary data (weight %, number % and frequency of occurrence %) were presented as means by size class as given for the first dataset with the addition of a 0-35 cm group (Gedamke, 2006). Sample sizes by size class were 0-35 cm n=25, 35-70 cm n=126, 70-105 cm n=52 and >105 cm n=70 (Figure A1 upper).

Food habits data were compared between the two datasets for each size class by generating pie charts of the data after grouping the prey into broad taxonomic categories (fish, shrimp, crab and other). Further comparison of the data was done using the multivariate statistical techniques of cluster analysis and multidimensional scaling. These techniques reduce the dimensionality of the data to show the similarities or differences between groups.

Prey Item Trends and Barndoor Skate Recovery

Trends in abundance for the top teleost prey items along with the barndoor skate abundance data on Georges Bank were plotted as stratified total estimates obtained during the NMFS autumn survey from 1963-2007. Similar plots were generated for the main prey fish and invertebrate species on Scotian Shelf (Div. 4VWX) using information gathered during DFO's summer research surveys during 1970-2008. Shrimp (*Pandalus borealis*) abundance information was obtained from Etter and Mohn (1987) and Koeller (pers. comm.) for the eastern Scotian Shelf and from Idoine (2006) for the Gulf of Maine. Similar invertebrate data from Georges Bank was not available.

Stratified abundances estimates were standardized using: $\frac{y_i - \bar{y}}{\sqrt{\frac{\sum (y_i - \bar{y})^2}{n-1}}}$ prior to plotting.

Results

Food Habits Data

The diet of barndoor skates is dominated by fish, and crustaceans (Tables A1, A5; Figure A2), however the proportions of these items change with body size (Tables A2, A3, A4, A6, A7, A8, A9; Figure A3). This strategy is characteristic of barndoor skate as ontogenetic dietary shifts are similar for all data used in this study, which represent not only spatial separation but temporal separation of nearly four decades (Figure A4). Specific regional differences in the main

crustacean being consumed are apparent as shrimp dominate on the Scotian Shelf and crabs dominate on Georges Bank. Perhaps this is due to differences in species composition, foraging habits, or seasonality but the underlying mechanism is currently unknown.

Small barndoor skate (<70 cm) are predominantly bottom feeders. They mainly consume shrimp (Pandailidae and Crangonidae) and crabs (Brachyura and Panguroidea) with fish constituting a maximum of only 1.9% of the diet (Tables A2, A6, A7). The most important shrimp prey on the Scotian Shelf are the Pandalid`s whereas Crangonid`s (*C. septemispinosa*) are the main shrimp consumed on Georges Bank. Regional differences may be due to the availability of species in the different areas as Pandalid`s (*P. borealis, P. montagui*) are common on the Scotian Shelf.

Large barndoor skate (>70 cm) consume substantially more fish than crustaceans (Tables A3, A4, A8, A9; Figure A3) which can represent >90% of the diet. Similar to the small barndoor skate the prey species composition differs by area. Large Scotian Shelf barndoor skate consume large proportions of silver hake (*Merluccius bilinearis*) and haddock (*Melanogrammus aeglefinus*) whereas those on Georges Bank consume sculpins (*Myoxocephalus* sp.), red hake (*Urophycis chuss*) and ocean pout (*Marozoarces americanus*) and in both areas they consume and herring (*Clupea harengus*).

Prey Abundance and Barndoor Skate Recovery

Comparing the increased abundance of barndoor skate in relation to some important prey species may provide context with which to evaluate the apparent species recovery. On Georges Bank, the collapse of the barndoor skate in the mid-1960s was also evident in several of their main prey species, red hake, ocean pout and herring (Figure A5). Recovery to above average levels can be seen as early as 1974 in red hake, and ocean pout, however, herring took a substantially longer time to recover and were not above average abundance until after the late 1980s (Figure A5). During the recent recovery (since 1995) of barndoor skate, both red hake and ocean pout have been at reduced abundance for much of the time whereas herring has been increasing (Figure A5).

Trends in barndoor skate abundance on the Scotian Shelf do not include the early collapse as standardized surveys were not performed prior to 1970. In 1978, barndoor skate were captured in high numbers during several sets thus inflating the abundance estimate for that time (Figure A6). Abundance of silver hake have been higher than average since the early 1980s, whereas herring and haddock have been high since the mid 1990s (Figure A6). Invertebrates have not been consistently monitored in our standard surveys leading to a short time series of data, however the trends suggests variable numbers of crab and shrimp throughout the last decade, with increases in shrimp in both the Gulf of Maine and Subdiv. 4Vs since 2002.

Overall, the abundance trends for prey species of barndoor skate are not consistent with the abundance trends of barndoor skate, suggesting that the availability of these prey species is not associated with the recent increase in barndoor skate.

Table A1. Prey items and food habits summary data of 133 barndoor skate captured during DFO research vessel surveys of the Scotian Shelf, 1963-1966.

Prey Item	Weight (%)	Frequency (%)
Fish		
Melanogrammus aeglefinus	3.2	1.5
Merluccius bilinearis	9.2	2.3
Sebastes sp.	2.3	3
Hippoglossoides platessoides	0.3	0.8
Clupea harengus	2.6	1.5
Argentina silus	1.7	0.8
Myctophidae	<0.01	0.8
Myoxocephalus octodecemspinosus	0.3	0.8
Artedidellus uncinatus	<0.01	0.8
Osteichthyes *C.*	0.2	0.8
Anguilla rostrata	0.9	0.8
Unidentified Fish	54.4	38.3
Shrimp		
Pandilidae	5.9	34.6
Crangonidae	0.3	6
Crab		
Brachyura S.	7.8	11.3
Paguroidea S.F.	0.9	4.5
Other		
Hippolytidae F.	<0.01	0.8
Homerus americanus	<0.01	0.8
Thalassinidae S.F.	0.2	0.8
Euphausiidae F.	0.2	3.8
Annelida	0.1	0.8
Gastropoda	0.1	2.3
Buccinium	0.2	0.8
Protobranchia	0.4	1.5
Illex illecebrosus	0.9	2.3
Octopoda O.	<0.01	0.8
Cestoda C.	<0.01	0.8
Unidentified Remains	1.2	1.5
Mucus	6.6	6.8

Table A2. Prey items and food habits summary data of 14 barndoor skate sized 35 to 70 cm captured during DFO research vessel surveys of the Scotian Shelf, 1963-1966.

Prey Item	Weight (%)	Frequency (%)
Fish		
Artediellus uncinatus	1.9	7.1
Shrimp		
Pandilidae	52.7	57.2
Crangonidae	10.2	21.3
Crab		
Brachyura S.	7.8	11.3
Panguroidea S.F.	1.9	7.1
Other		
Euphausiidae F.	3.7	7.1
Gastropoda	1.9	7.1
Illex illecebrosus	9	7.1
Octopoda O.	1.9	7.1

Table A3. Prey items and food habits summary data of 64 barndoor skate sized 70 to 105 cm captured during DFO research vessel surveys of the Scotian Shelf, 1963-1966.

Prey Item	Weight (%)	Frequency (%)
Fish		
Melanogrammus aeglefinus	1.0	1.6
Sebastes sp.	4.1	1.6
Hippoglossoides platessoides	1.5	1.6
Myoxocephalus octodecemspinosus	1.6	1.6
Anguilla rostrata	4.1	1.6
Unidentified Fish	48.4	38.3
Shrimp		
Pandilidae	18.5	46.9
Crangonidae	1.1	7.8
Crab		
Brachyura S.	9.9	12.5
Panguroidea S.F.	3.8	7.8
Other		
Euphausiidae F.	0.3	4.7
Annelida	0.2	1.6
Gastropoda	0.2	3.1
Illex illecebrosus	1.7	1.6
Octopoda O.		
Cestoda C.	<0.1	1.6
Unidentified Remains	2.8	1.6
Mucus	0.2	1.6

Table A4. Prey items and food habits summary data of 54 barndoor skate sized >105 cm captured during DFO research vessel surveys of the Scotian Shelf, 1963-1966.

Prey Item	Weight (%)	Frequency (%)
Fish		
Melanogrammus aeglefinus	3.9	1.9
Merluccius bilinearis	11.9	5.6
Sebastes sp.	1.9	5.6
Clupea harengus	3.3	3.7
Argentina silus	2.2	1.9
Myctophidae	<0.1	1.9
Osteichthyes *C.*	0.2	1.9
Unidentified Fish	56.3	46.3
Shrimp		
Pandilidae	2.0	14.5
Crab		
Brachyura S.	7.2	11.1
Panguroidea S.F.	0.2	1.9
Other		
Homerus americanus	<0.1	1.9
Euphausiidae F.	0.2	1.9
Buccinum	0.2	1.9
Protobranchia	0.6	1.9
Illex illecebrosus	0.6	1.9
Unidentified Remains	0.8	1.9
Mucus	8.5	14.9

Table A5. Food habits data of 273 barndoor skate collected on Georges Bank (Gedamke, 2006).

Prey item	Number (%)	Weight (%)	Frequency (%)
Fish			
Scomber scombrus	0.02	0.33	0.37
Clupea harengus	0.59	10.9	6.59
Myoxocephalus sp.	0.43	5.15	5.13
Urophycis sp.	0.21	6.4	3.3
Urophycis chuss	0.12	5.91	1.1
Macrozoarces americanus	0.14	14.82	2.2
Limanda ferruginea	0.15	2.51	0.73
Paralichthys dentatus	0.02	0.98	0.37
Peprilus triacanthus	0.02	0.34	0.37
Hemitripterus americanus	0.05	1.38	0.73
Paralichthys oblongus	0.07	1.72	0.73
Unidentified fish	0.05	3.32	7.33
Unidentified flatfish	0.17	2.94	2.2
Shrimp			
Crangon septemspinosa	34.61	1.64	38.83
Pandalus propinquus	0.66	0.01	2.2
Dichelopandalus leptocerus	2.44	0.12	4.76
Crab			
Pagurus acadianus	20.79	14.43	38.46
Pagurus pubescens	0.05	0.01	0.73
Cancer irroratus	29.6	17.83	54.95
Cancer borealis	2.13	4.14	6.59
Cancer sp.	0.12	0.06	0.37
Unidentified crab	0.43	0.31	4.4
Other			
Unidentified decapod	0.28	0.19	4.4
Unidentified amphipod	1.11	0.08	1.83
Unidentified isopod	0.66	0.04	1.83
Unidentified barnacle	0.02	0	0.37
Unidentified snail	1.07	0.08	8.06
Unidentified bivalve	0.05	0	0.73
Unidentified nematode	2.47	0.02	13.19
Unidentified trematode	0.07	0	0.37
Unidentified Organic Matter	0.92	3.62	14.29

Table A6. Food habits data of 25 small barndoor skate (length range 20-35 cm) collected on Georges Bank (Gedamke, 2006). Data are separated by sex.

Prey item	Number (%)		Weight (%)		Frequency (%)	
	M	F	M	F	M	F
Shrimp						
Crangon septemspinosa	65.35	80.53	89.7	50.94	53.33	70
Dichelopandalus leptocerus	33.66	16.81	8.37	48.21	26.67	30
Crab						
Cancer irroratus	-	0.88	1.84	-	-	10
Other						
Unidentified crab	0.99	-	-	0.85	6.67	-
Unidentified nematode	-	1.77	0.09	-	-	10

Table A7. Food habits data of 126 barndoor skate (length range 35-70 cm) collected on the southern Georges Bank (Gedamke, 2006). Data are separated by sex.

Prey item	Number (%)		Weight (%)		Frequency (%)	
	M	F	M	F	M	F
Fish						
Unidentified fish	0.08	0.07	0	0.05	1.72	1.45
Unidentified flatfish	-	0.14	-	0.03	-	1.45
Shrimp						
Crangon septemspinosa	53.97	42.94	18.68	9.86	74.14	60.87
Pandalus propinquus	0.08	1.63	0.09	0.09	24.14	4.35
Dichelopandalus leptocerus	1.57	1.63	0.89	0.23	1.72	4.35
Crab						
Pagurus acadianus	5.54	13.5	8.78	23.28	24.14	40.58
Pagurus pubescens	-	0.07	-	0.04	-	1.45
Cancer irroratus	35.29	33.72	62.51	60.27	77.59	69.57
Cancer borealis	1.32	2.17	2.01	4.56	3.45	4.35
Cancer sp.	0.41	-	1.29	-	1.72	-
Unidentified crab	0.08	0.2	0.15	0.01	1.72	1.45
Other						
Unidentified isopod	-	0.34	-	0.05	-	2.9
Unidentified snail	0.17	0.81	0.03	0.07	1.72	8.7
Unidentified bivalve	0.08	-	0.03	-	1.72	-
Unidentified nematode	0.91	2.37	0.08	0.05	10.34	17.39
dentified Organic Matter	0.5	0.41	5.46	1.4	10.34	8.7

Table A8. Food habits data of 52 barndoor skate (length range 70-105 cm) collected on the southern Georges Bank (Gedamke, 2006). Data are separated by sex.

Prey item	Number (%)		Weight (%)		Frequency (%)	
	M	F	M	F	M	F
Fish						
Clupea harengus	0.78	1	10.56	8.38	5.03	11.11
Myoxocephalus sp.	0.39	-	4.67	-	6.06	-
Urophycis sp.	0.39	1	3.96	12.6	6.06	11.11
Urophycis chuss	0.58	-	11.08	-	3.03	-
Macrozoarces americanus	0.19	-	26.31	-	3.03	-
Peprilus triacanthus	0.19	-	1.58	-	3.03	-
Hemitripterus americanus	-	0.5	-	14.66	-	5.56
Unidentified fish	0.97	-	1.94	-	12.12	-
Shrimp						
Crangon septemspinosa	1.17	2	0.03	0.02	9.09	5.56
Pandalus propinquus	-	0.5	-	0.01	-	5.56
Dichelopandalus leptocerus	-	1.5	-	0.17	-	5.56
Crab						
Pagurus acadianus	49.12	32	15.83	10.46	57.58	66.67
Cancer irroratus	34.5	41.5	18.55	28.38	63.64	77.78
Cancer borealis	1.36	10	1.11	14.68	9.09	22.22
Other						
Unidentified crab	0.19	1	0.28	0.28	3.03	11.11
Unidentified decapod	0.39	1	0.01	0.01	6.06	11.11
Unidentified snail	2.53	2	0.05	0.19	15.15	11.11
Unidentified bivalve	0.19	-	0	-	3.03	-
Unidentified nematode	5.26	1	0.01	0.01	24.24	11.11
Unidentified Organic Matter	1.75	5	4.01	10.13	27.27	55.56

Table A9. Food habits data of 70 barndoor skate (length >105 cm) collected on southern Georges Bank (Gedamke, 2006). Data are separated by sex.

Prey item	Number (%)		Weight (%)		Frequency (%)	
	M	F	M	F	M	F
Fish						
Scomber scombrus	0.5	-	1.48	-	3.33	-
Clupea harengus	3.94	2.7	13.32	13.92	23.33	20
Myoxocephalus sp.	6.97	0.49	13.36	3.25	33.33	5
Urophycis sp.	1.49	0.49	10.34	5.88	10	5
Urophycis chuss	1	-	15.68	-	6.67	-
Macrozoarces americanus	1	0.74	15.42	16.33	6.67	7.5
Limanda ferruginea	0.5	0.25	4.29	4.42	3.33	2.5
Paralichthys dentatus	-	0.25	-	2.79	-	2.5
Hemitripterus americanus	0.5	-	0.13	-	3.33	-
Paralichthys oblongus	1.49	-	7.65	-	6.67	-
Unidentified fish	5.47	1.97	8.06	5.15	36.66	20
Unidentified flatfish	1.49	0.49	4.89	5.26	10	5
Shrimp						
Crangon septemspinosa	2.99	0.25	0	0	3.33	2.5
Pandalus propinquus	1	-	0.01	-	3.33	-
Dichelopandalus leptocerus	1.99	-	0.03	-	3.33	-
Crab						
Pagurus acadianus	8.96	68.06	1.02	22.11	20	65
Cancer irroratus	8.96	11.3	2.87	9.81	20	37.5
Cancer borealis	0.5	3.44	0.23	5.92	3.33	12.5
Unidentified crab	3.48	0.74	0.47	0.33	13.33	5
Other						
Unidentified decapod	1	1.47	0.01	0.52	6.67	15
Unidentified amphipod	23.38	-	0.35	-	16.67	-
Unidentified isopod	9.95	0.74	0.14	0.01	6.67	2.5
Unidentified barnacle	-	0.25	-	0.01	-	2.5
Unidentified snail	-	3.44	-	0.13	-	20
Unidentified nematode	10.95	1.23	0	0.03	13.33	7.5
Unidentified trematode	1.49	-	0	-	3.33	-
Unidentified Organic Matter	1	1.47	0.25	4.11	6.67	15

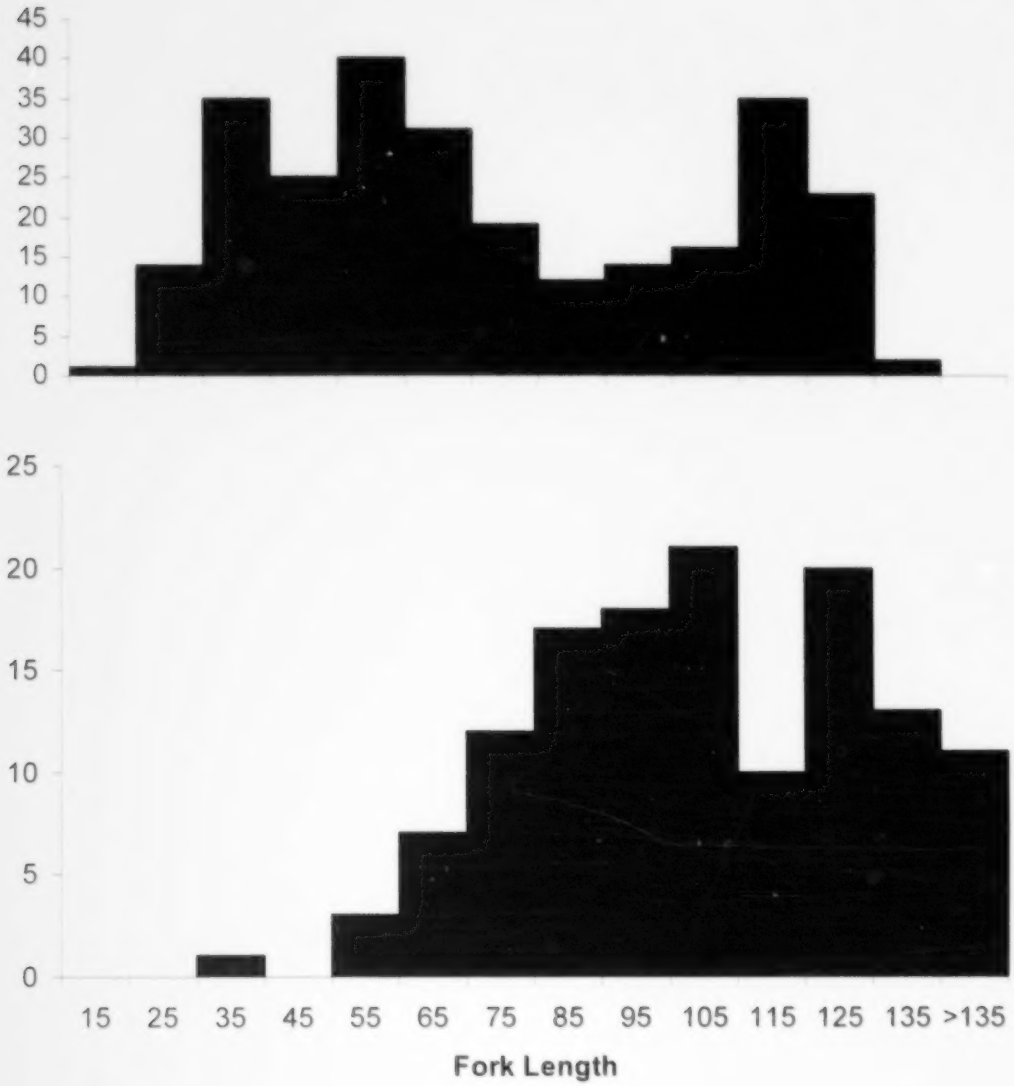


Figure A1. Length frequency histogram of stomach sampled barndoor skate from Georges Bank (upper) and the DFO (lower) surveys.

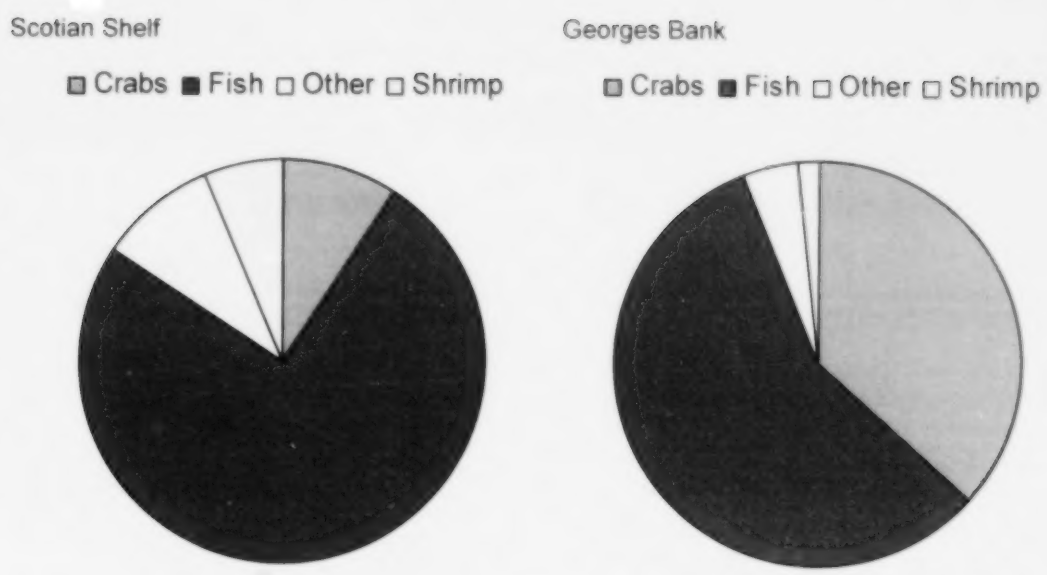


Figure A2. Comparison of weight (%) of broad prey items from barndoor skate on the Scotian Shelf and Georges Bank.

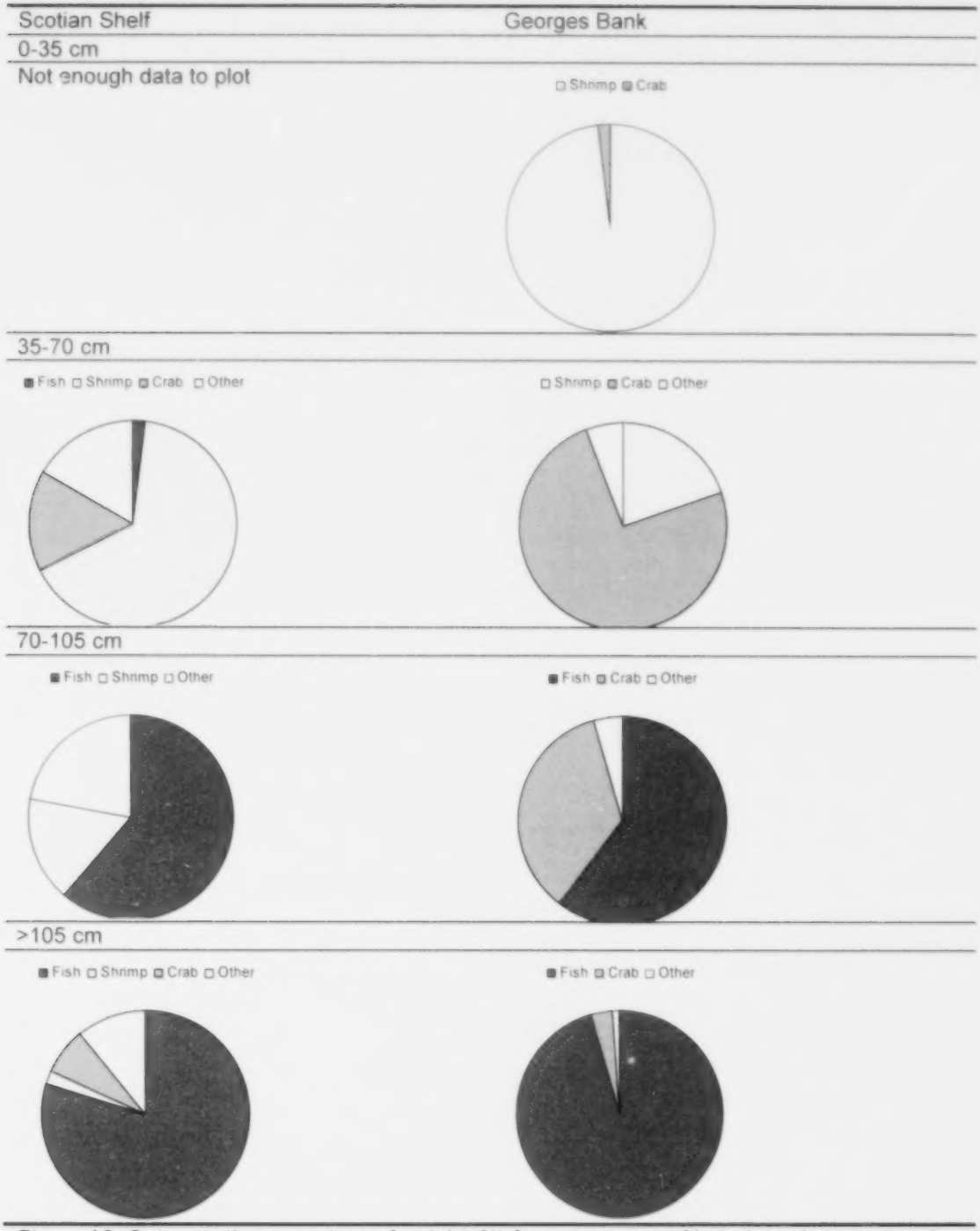


Figure A3. Ontogenetic comparison of weight (%) for prey groups of barndoor skate captured on the Scotian Shelf and Georges Bank.

Figure A4. Multidimensional scaling plot of food habits data for Scotian Shelf (blue inverted triangles) and Georges Bank (green triangles) separated by size class. Labels on plot indicate size class.

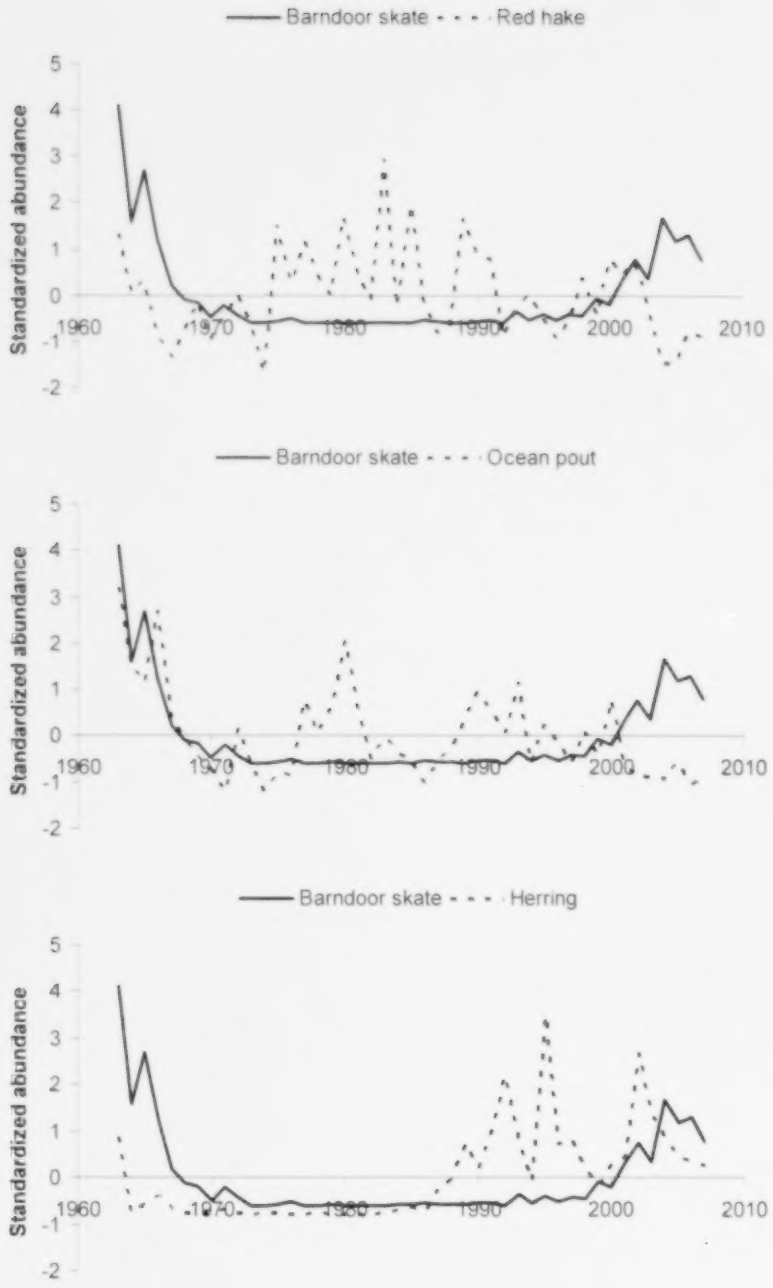


Figure A5. Trends in standardized abundance for the prey fish of barndoor skate on Georges Bank. Data from the autumn NMFS stratified survey.

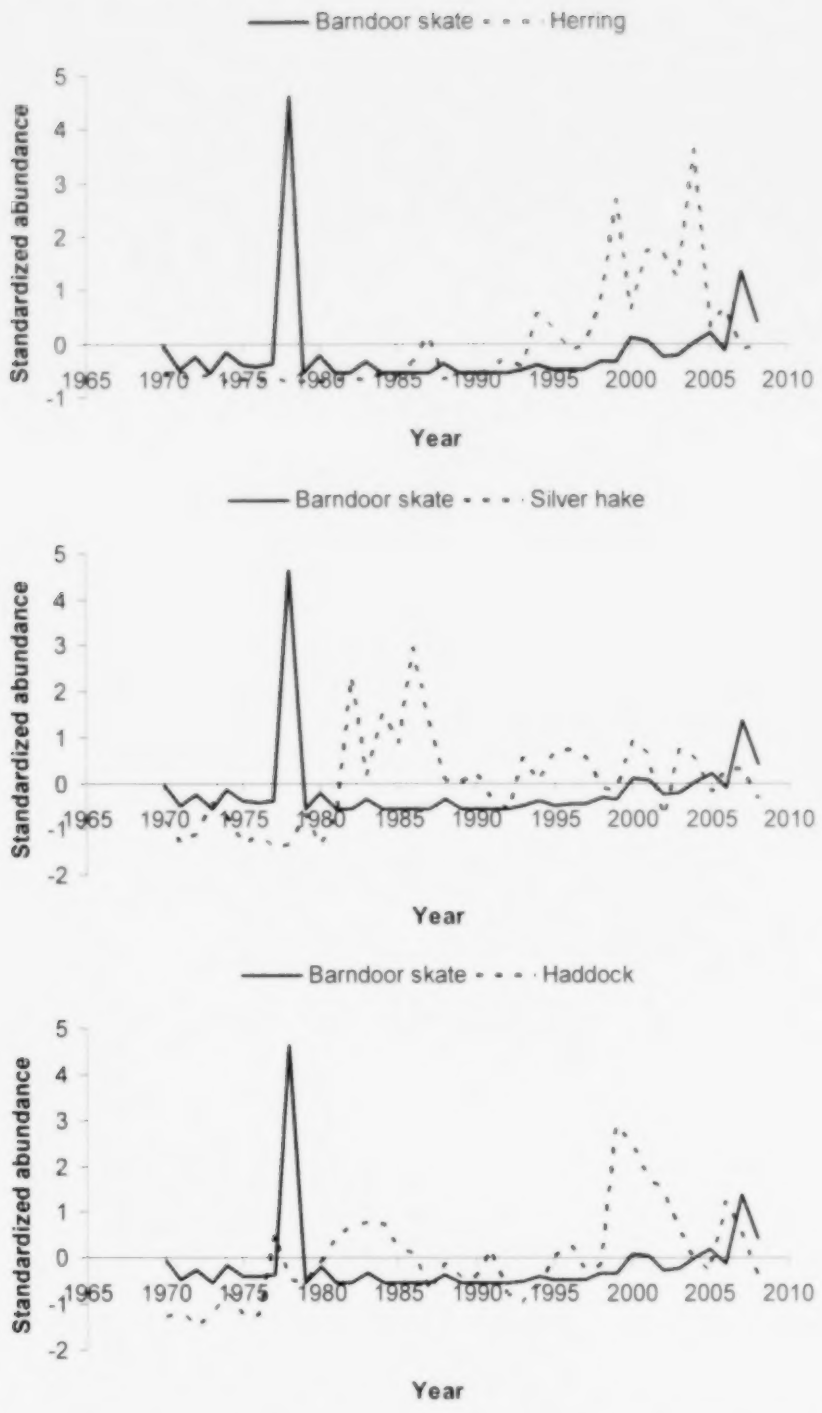


Figure A6. Trends in standardized abundance for the prey fish of barndoor skate on the Scotian Shelf. Data from the DFO summer RV survey.

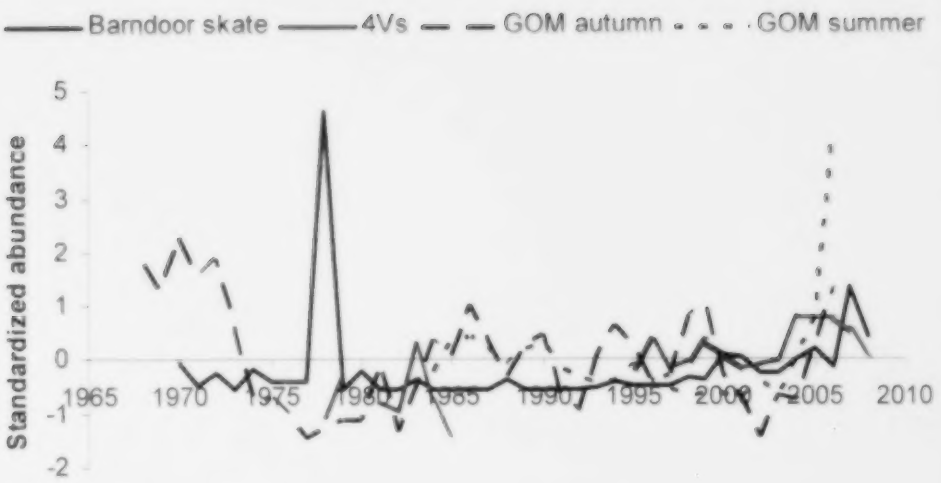


Figure A7. Trends in abundance of barndoor skate and shrimp from the Scotian Shelf (Subdiv.4Vs; Etter and Mohn, 1987, P. Koeller, pers. comm.) and the Gulf of Maine autumn and summer data series (Idoine 2006).

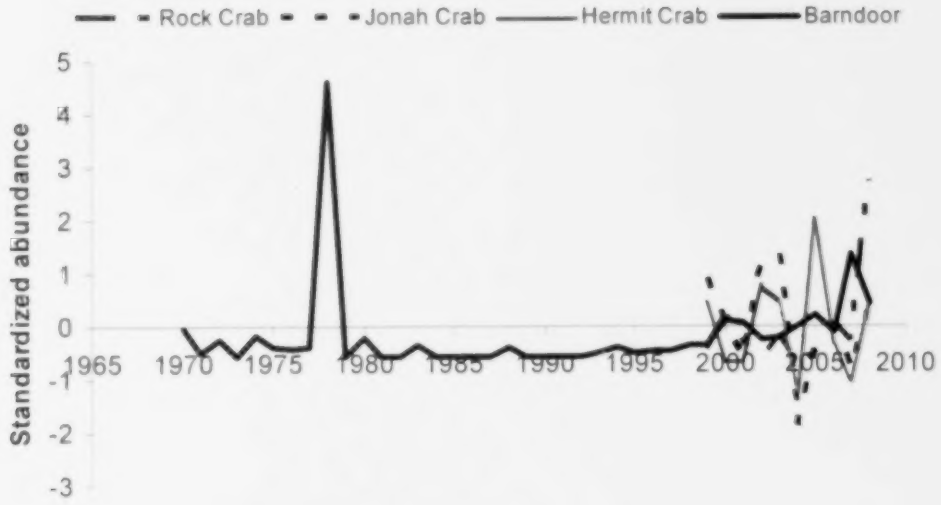


Figure A8. Trends in standardized abundance of barndoor skate and crab species from the Scotian Shelf (Div. 4VWX).